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INITIAL PROTOTYPE EVALUATION OF EXPANDABLE CARCASS-REPLACEABLE TREAD TIRE FOR C-130 AIRCRAFT

THE B.F. GOODRICH COMPANY
AKRON, OHIO 44318

JANUARY 1975

TECHNICAL REPORT AFFDL-TR-74-131

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The initial prototype evaluation of the expandable carcass-replaceable tread tire for the C-130 aircraft was completed. The evaluation was concerned with the design, manufacture, and performance of various replaceable tread designs, both bias and radial carcasses, in the 20.00-20 size. Derailment, the area of greatest concern on the 6.00-6/8 PR size, was not a problem with the 20.00-20/26 PR tires evaluated. Four completely new and unexpected major performance problems were encountered. The first, belt splitting,

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Manufacturing difficulties were also encountered. These were classified as carcass shoulder blisters, curing bladder expansion irregularities and exposed sidewall cords. Improvements were made but these problems still exist. Current manufacturing techniques do not lend themselves to large volume production of 20.00-20 expandable carcass-replaceable tread tires.

Based on the results of the Phase II program recommendations are made for resolving the performance and manufacturing problems which would ultimately lead to production capability and performance acceptance.

INITIAL PROTOTYPE EVALUATION OF EXPANDABLE CARCASS-REPLACEABLE TREAD TIRE FOR C-130 AIRCRAFT

E. M. Tatarzycki and J. W. Pond

FOREWORD

This report was prepared by E. M. Tatarzycki and J. W. Pond of The B. F. Goodrich Company under USAF Contract F33615-72-C-1349. The work was conducted under the direction of the Vehicle Equipment Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, H. K. Brewer, (AFFDL/FEM) Project Engineer. This report covers work performed in Phase II between May 1972 and April 1974 to design, manufacture, and evaluate a series of initial prototypes in the 20.00 x 20/26 PR Type III aircraft tire size. Previous Phase I efforts are reported in AFFDL-TR-73-84, "Expandable Carcass-Replaceable Tread Tire Development for C-130 Aircraft". The Phase I report describes efforts to determine the cause of derailment, to develop a theory for predicting derailment, and to build replaceable tread tires which would not derail. Phase III efforts in the refinement of the best design for operational use will be described in a separate report. The report was submitted by the authors October 1974 for publication as a technical report.

Publication of this technical report does not constitute Air Force approval of the report's finding or conclusions. It is published only for the exchange and stimulation of ideas.

FOR THE COMMANDER

AIVARS V. PETERSONS
Actg Chief, Mechanical Branch
Vehicle Equipment Division
Air Force Flight Dynamics Laboratory

ABSTRACT

The initial prototype evaluation of the exapndable carcass-replaceable tread tire for the C-130 aircraft was completed. The evaluation was concerned with the design, manufacture and performance of various replaceable tread designs, both bias and radial carcasses in the 20.00-20 size. Derailment, the area of greatest concern on the 6.00-6/8 PR size, was not a problem with the 20.00-20/26 PR tires evaluated. Four completely new and unexpected major performance problems were encountered. The first, belt splitting, has been solved. The second, chafing, appears to be resolved but will require additional testing. The remaining two, tread band breakage and ply separations in the belt, have not been resolved.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Page

Page

LIST OF TABLES

Section I

INTRODUCTION

The Air Force has recognized that a special tire design, that is a carcass and a replaceable tread, would have advantages in the areas of tire performance, logistics, and aircraft maintenance provided that such an expandable carcass - replaceable tread tire could be manufactured to meet military aircraft tire performance and acceptance standards.

The present program for development of a 20.00-20/26 PR expandable carcass-replaceable tread tire is based on work done for the Air Force Flight Dynamics Laboratory under Contract F33615-69-C-1395. This completed work demonstrated the performance capability of the 6.00-6/8 PR radial carcass-replaceable tread tire concept.

Due to the potential advantages that would result if a large size replaceable tread tire could be developed, and because of the success under Contract 1395, a three phase program was initiated under USAF Contract F33615-72-C-1349. The objective is to qualify, for operational use, a 20.00-20/26 PR expandable carcass-replaceable tread tire for the C-130 aircraft. This attempt will use the information gained on the 6.00-6/8 PR tire and apply it to the 20.00-20/26 PR tire. The scope of Phase I was to establish the causes and possible remedy of tread band derailment on bias carcass-replaceable tread tires. This effort was limited to the 6.00-6/8 PR size and has been completed and reported. Phase II has been completed and was concerned with the design, manufacture, and performance of various prototype replaceable tread designs, both bias and radial carcasses, in the 20.00-20 size. Phase III has not yet been initiated; it will deal with the optimization and qualification of the most promising prototype design of Phase II.

This technical report is a Status Report covering the entire manufacturing and evaluation program of Phase II. The objective of Phase II was to design and manufacture a total of eight different expandable carcass and tread band configurations in the 20.00-20 size.

Prior to Phase II all effort on the expandable carcass-replaceable tread tire was limited to the 6.00-6 size. In the initial program, Contract 1395, this concept was determined to be feasible for small size, Type III, aircraft tires. In the current contract derailment was believed to provide the major obstacle. In Phase I, the successful determination of the causes of derailment and the subsequent development of a theory enabled us to predict when derailment would occur on 6.00-6 yawed rolling replaceable tread tires of both radial and bias constructions. This was

based on certain coefficients which were determined experimentally for the 6.00-6 size only. In predicting derailment conditions for any other size, including the 20.00-20, we recognized and stated that it would be necessary to determine these coefficients again. Success, in the initial derailment tests and lack of adequate equipment relegated the determination of coefficients for the 20.00-20 size to minor significance.

During the course of the Phase II program we encountered four major performance problems. All were new and unexpected because they had not occurred on the 6.00-6 size. The first such problem was splitting of the tread band. In all the extensive tests conducted on the 6.00-6 size both at B.F. Goodrich and AFFDL this problem never occurred. In seeing the split belts on the 20.00-20 but not on the 6.00-6 size we realized that the design of a successful expandable carcass replaceable tread tire in large sizes involved more than simple extrapolation from the 6.00-6 tire. A small change in the construction of the 20.00-20 tread band eliminated the belt splitting.

The second major performance problem on the 20.00-20/26 PR was chafing at the interface between carcass and tread band. Most of the Phase II effort was directed toward solving this problem. Many construction, geometry and size modifications were tried. Presently, it appears that we have been able to reduce chafing; but to determine whether it has been completely eliminated will require additional testing.

The third and fourth major performance problems appeared when we made the change which helped to reduce the chafing. Tread band breakage and ply separations in the belt became the primary failure modes. Both of these problems have not been resolved to date.

The Phase II program has been completed; its objective to design, manufacture and subsequently evaluate for tread band retention and carcass durability a total of eight different expandable carcass and tread band configurations in the 20.00-20 size has been met. We have designed, manufactured and evaluated a total of eleven different carcass configurations and twenty-three tread band configurations.

Section II

TECHNICAL PROGRAM

The effort in Phase II involved the design, manufacture, and evaluation of various prototype replaceable tread tire designs including both bias and radial carcasses in the 20.00-20 size. A total of eleven different carcass and twenty-three different tread band configurations were manufactured and tested. Most of these changes were made to eliminate four totally new and unexpected problems, i.e., tread band splitting, chafing at the interface, belt breakage and loss of tread rubber. Our prior experience with the 6.00-6/8 PR replaceable tread tire indicated that only tread band stability was a major concern. Thus our program for Phase II was directed to prevent derailment in the 20.00-20/26 PR size.

Based on our work in Phase I with the 6.00-6/8 PR replaceable tread tire we designed the 20.00-20/26 PR size on the basis of:

1) meeting MIL-T-5041F dimensional requirements
2) extrapolating from the 6.00-6/8 PR replaceable tread tire design
3) using the conventional 20.00-20/26 PR tire design

Difficulties were encountered in manufacturing. They may be categorized as follows:

1) Liner blisters in the shoulder
2) Curing bladder expansion
3) Exposed sidewall cords

Although improvements were made during the course of the Phase II program the above problems still exist. They are not viewed as unsurmountable, but will require additional effort.

Major performance problems were encountered in the following areas:

1) tread band splitting
2) chafing
3) tread band breakage
4) ply separations in the belt

Each of these was new and totally unexpected. Tread band splitting was eliminated early in Phase II. It appears that we may have resolved the

chafing problem but many additional tests must be conducted to completely verify this. Tread band breakage appears to be more complex than simply a case of insufficient cords. The ply separations may be caused by a strain incompatibility within the tread band itself. In both cases, however, the dynamics of the carcass and tread band must be better understood.

2.1 MANUFACTURE

2.1.1 Carcasses

A total of 44 carcasses were manufactured as listed in Table I. All were defective due to at least one reason, or in most cases, several reasons including:

1. Liner blisters in the shoulder area
2. Curing bladder expansion
3. Exposed cords in the sidewall, and in the shoulder area

Considerable efforts were made to improve the conditions which resulted in manufacturing defects. Changes were made in manufacturing procedures, processes and equipment but only with moderate success. The shoulder blisters and the exposed sidewall cords are all probably caused by the carcass shape. The curing bladder expansion is the non-uniform expansion of the bladder in relation to the carcass.

The exposed cord condition has not been solved and no concerted effort toward a solution has been made, since we believe that this problem, at the present time, is of secondary importance. The primary cause of this condition is the configuration of the carcass mold.

In summary, improvements have been made in reducing manufacturing defects. However, these improvements have not achieved total resolution. The quality level needs improvement in order to meet the current stringent Air Force standards. The greatest improvement was obtained by use of the restrictive nylon piles in the crown area, permitting the use of a higher shaping pressure. However, the use of such plies may have an adverse effect on tread band to carcass interference.

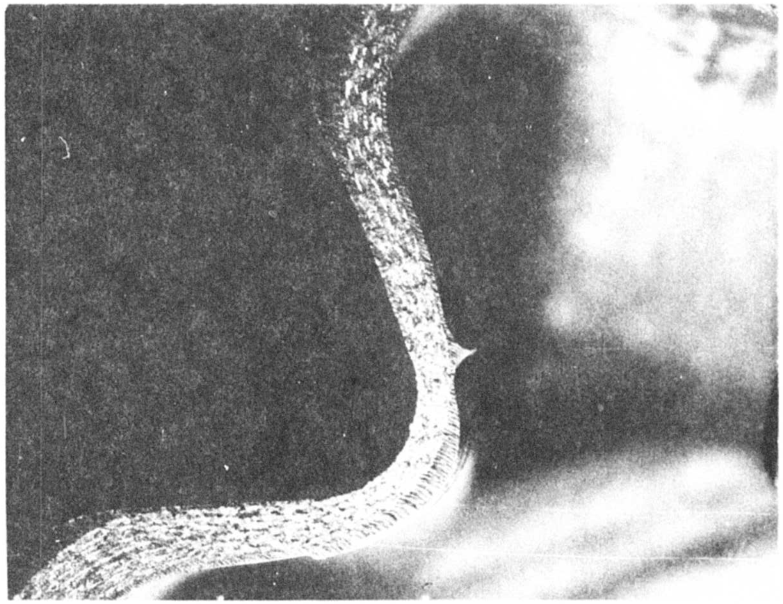

Figure 1. Photograph of a Carcass Defect - Curing Bladder Expansion.

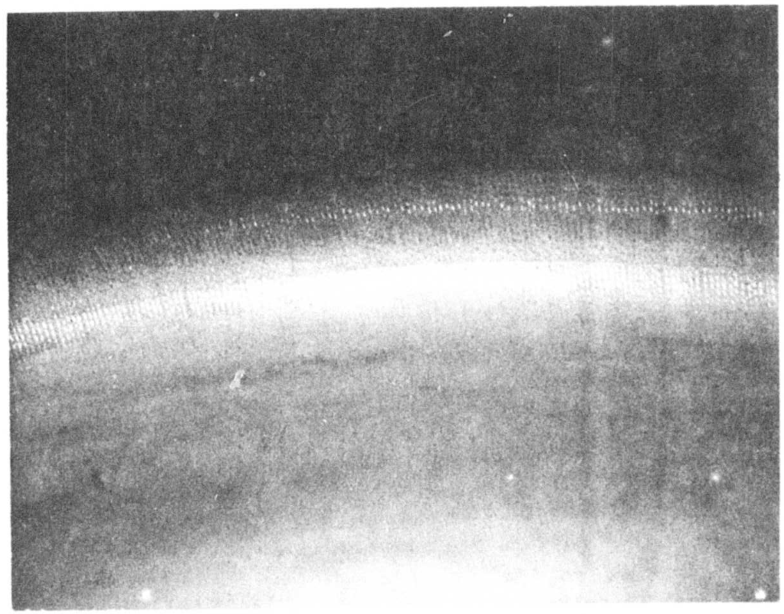

Figure 2. Photograph of a Carcass Defect - Exposed Sidewall Cords

Table I - Description of all 20.00-20/26 PR Expandable Carcasses Manufactured in Phase II [1]

Specification Number	Number Manufactured	Cord Angle	Remarks
N51-0210	2	55°	
N51-0211	10	72°	
N51-0212	2	85°	
N51-0229	2	55°	liner precured
N51-0229 A	2	62°	
N51-0230	2	64°	liner precured
N51-0230 A	4	68°	liner precured
N51-0231	2	72°	liner precured
N51-0231 A	6	74°	liner precured
N51-0231 B [2] [3]	6	74°	liner precured evaluate bladderless cure evaluate crown restriction
N51-0231 C [2] [3]	6	74°	liner precured evaluate bladderless cure evaluate crown restriction
TOTAL	44		

Note (1) Construction of each carcass consisted of 10 plies of 840/2 and 1680/2 nylon cord.

Note (2) Bladderless curing attempted on two carcasses. Steam leaks into carcass beads made them unsatisfactory for use. Remaining ones were cured with a bladder.

Note (3) Crown restriction, used on three carcasses, improved shaping and molding.

2.1.2 Tread Bands

At the beginning of the program we anticipated the need to alter construction features, size and even the geometry of the tread bands. Thus it was decided to perform the building on a non-production scale using manual techniques and a simple but adjustable, laboratory building drum. Curing was performed in a conventional two piece tire mold using a bladder. Figure 3 shows a photograph of the laboratory building drum. Attention is called to the curvature which made it necessary to apply the circumferential cords in tape form, 1/4 inch wide. The procedure was quite slow usually requiring one man about one week to complete the construction of a single belt.

Table II lists all the tread band which were fabricated during Phase II. A total of thirty-one tread bands were built and cured including twenty-three different designs. Although rayon was an acceptable cord material in the 6.00-6 tread band it resulted in an extremely heavy, thick 20.00-20 tread band. In combination with the carcass, the weight of the assembled tire exceeded MIL-T-5041 F requirements. Thus, we decided to reduce the weight of the tread band by reducing the number of plies from ten to six and eventually to four. The use of Fiber B in lieu of rayon enabled us to achieve a weight reduction of 25 pounds.

We were able to change construction features quite easily as shown in Table II. Contour and size modifications were considerably more difficult because it was not possible to make mold changes. Consequently, we had to work with the mandrel building it up to provide the needed contour or diameter. The first twenty-three tread bands were all cured in the same mold. A second mold four inches smaller in diameter and one inch narrower was fabricated enabling the last eight belts to be cured in it. The latter mold was made intentionally small in both diameter and width to permit future recutting if necessary.

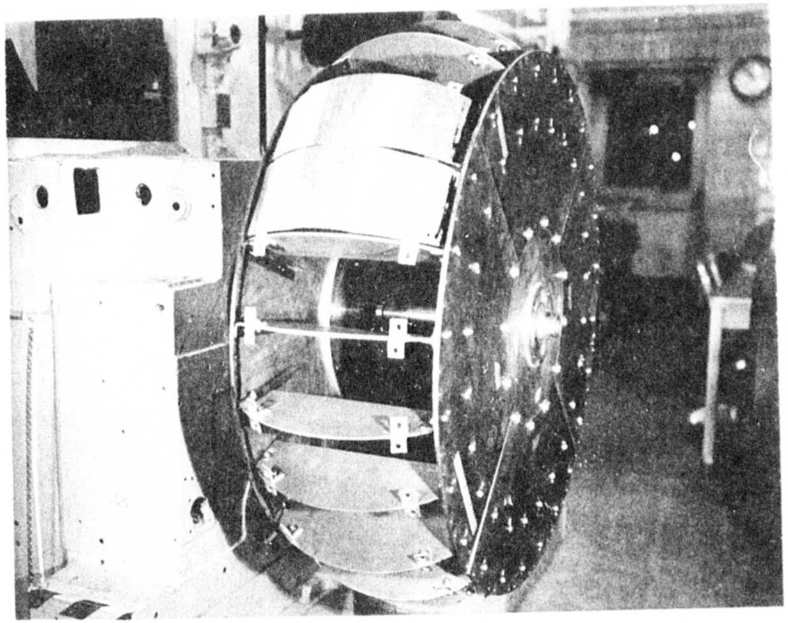

Figure 3. Photograph of Laboratory Building Drum for 20.00-20 Tread Bands.

Table II. Description of all 20.00-20 Tread Bands Fabricated in Phase II

Serial No.	Material	No. of Plies	Ply Layup	Belt Width	Belt Inside Crown Daimeter	Tread Radius
R51-0213-1	Rayon	10	0° + 4" wide 58° each edge	16.25	52.16	12.75
	Rayon	10	"	16.25	52.08	
	Fiber B	6	"		52.16	
R51-0213-2	Rayon	10	"		52.16	
	Fiber B	6	"		52.60	
R51-0213-3	Rayon	10	"		41.80	
R51-0213-4	Rayon	10	"		41.84	
R51-0213-5	Fiber B	6	"		52.40	
R51-0213-6	Rayon	10	"		51.84	
R51-0213-7	Rayon	10	"		51.80	
R51-B-251-1	Rayon	10	90-0-0-0-0-0-0-0-0-0-0		52.16	
R51-B-235-1	Rayon	10	+70-70-0-0-0-0-0-0-0-0-0-0		52.16	
B51-B-257-1	Fiber B	7	90-0-0-0-0-0-0-0-0		52.52	
B51-B-257-2	Fiber B	7	90°-0-0-0-0-0-0-0		52.52	
B51-B-263-1	Fib B	7	0-0-0-0-90-0-0-0		52.52	
B51-B-264-1	Fib B	4	0-0-90-0-0		53.0	
B51-B-266-1	Fib B	4	70-70-0-0-0-0		52.72	
B51-B-268-1	Fib B	4	0-0-0-0-90		52.84	
B51-B-275-1	Fib B	4	0-0-0-0-90		52.16	
B51-B-276-1	Fib B	4	0-0-0-0-90		50.45	16
BW51-B-274-1	Fib B	4	0-0-90-0-0 wire at edges		52.84	12.75
B51-B-276-2	Fib B	4	0-0-0-0-90		49.86	
B51-B-275-2	Fib B	4	0-0-0-0-90		51.72	
B51-B-297-1	Fib B	4	0-0-0-0-90	16.25	48.62	
B51-B-298-1	Fib B	4	0-0-0-0-90	16	48.86	
B51-B-298-2	Fib B	4	0-0-0-0-90	15.75	48.82	
B51-B-305	Fib B	6	0-0-0-0-0-0-90	15.75	48.66	
B51-B-306	Fib B	7	0-0-0-0-0-0-0-90	15.75	48.58	
B51-B-307	Fib B	6	0-0-0-0-90-0-0	15.75	48.62	
B51-B-308	Fib B	6	0-0-0-0-0-0-90±60° 4"wide	15.5	48.58	
B51-B-317	Fib B	8	±25° built on flat drum	16	48.64	

2.2 PERFORMANCE EVALUATION

2.2.1 Dimensional Measurements

Of the first 20.00-20 carcasses manufactured, three were selected for measurement. Each was constructed with a different cord angle. Table III identifies the carcasses and identifies their cord angles.

Table III. Three Carcasses and Their Cord Angles

Carcass Serial Number	N51-0210	N51-0211	N51-0212
Carcass cord angle	55°	72°	85°

Each of the above three carcasses was inflated at several inflation pressures and measured. These measurements were needed to establish the effect of carcass cord angle on inflated carcass circumference and eventually on the amount of interface between carcass and tread band. Our prior work under Phase I showed that this interference should be maximized to prevent derailment. Tables IV and V show the results of these measurements as do Figures 4, 5, and 6.

Table IV. Circumference of 20.00-20 Expandable Carcass Without Tread Band with Bias Angles as Shown (units in inches)

Pressure	55° Crown	55° Shoulder	72° Crown	72° Shoulder	85° Crown	85° Shoulder
0	134-3/4	134-3/4	135.1	134.1	134-3/4	134-3/4
5	149	143				
10	160.5	147	163		166	148
15	163.5	148.2	164.5	147	168.5	
20	164.5		165.2	147	169	149
25	165.2		167	147.5	170	
30	165.2	149	168.3	148.3	171	150
60	168.8	151	170.5	150		
100	172		173.7	151	175.5	153
125	174.6		176		179	

Table V. Circumferential Interference of Three 20.00-20 Replaceable Tread Tires at 125 psi Inflation Pressure

Tire No.	Bias Angle	Outside Carcass Circumference	Inside Tread Band Circumference	Interference at Circumference
N51-0210	55°	174.6	164-1/2	10.1
N51-0211	72°	176	164-1/2	11.5
N51-0212	85°	179	164-1/2	14.5

Of the three carcasses the greatest interference was provided by the 85° carcass. But, as discussed previously, it was also the most difficult to manufacture.

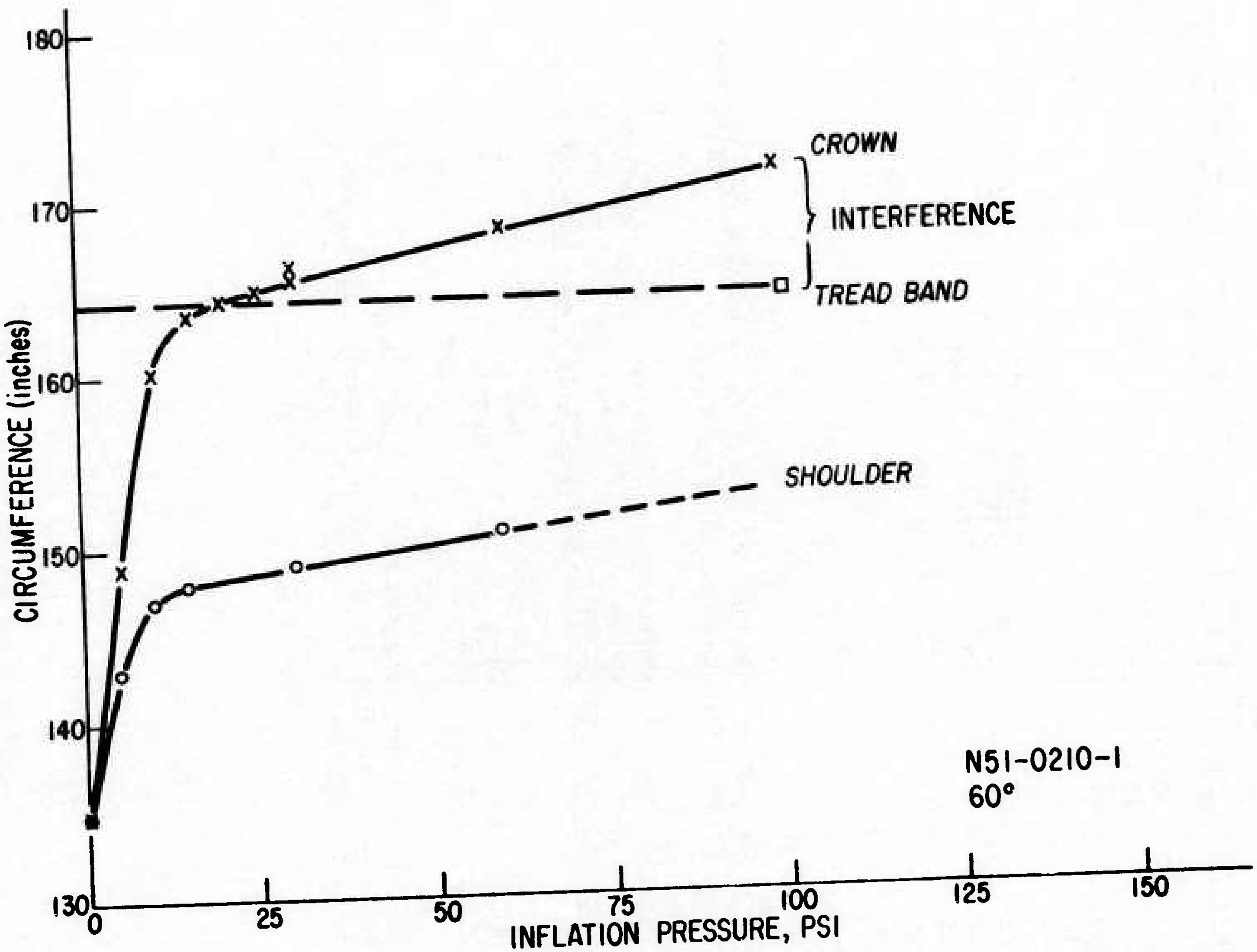

Figure 4. CIRCUMFERENCE of 55° CARCASS WITHOUT ITS BELT as a FUNCTION of INFLATION PRESSURE

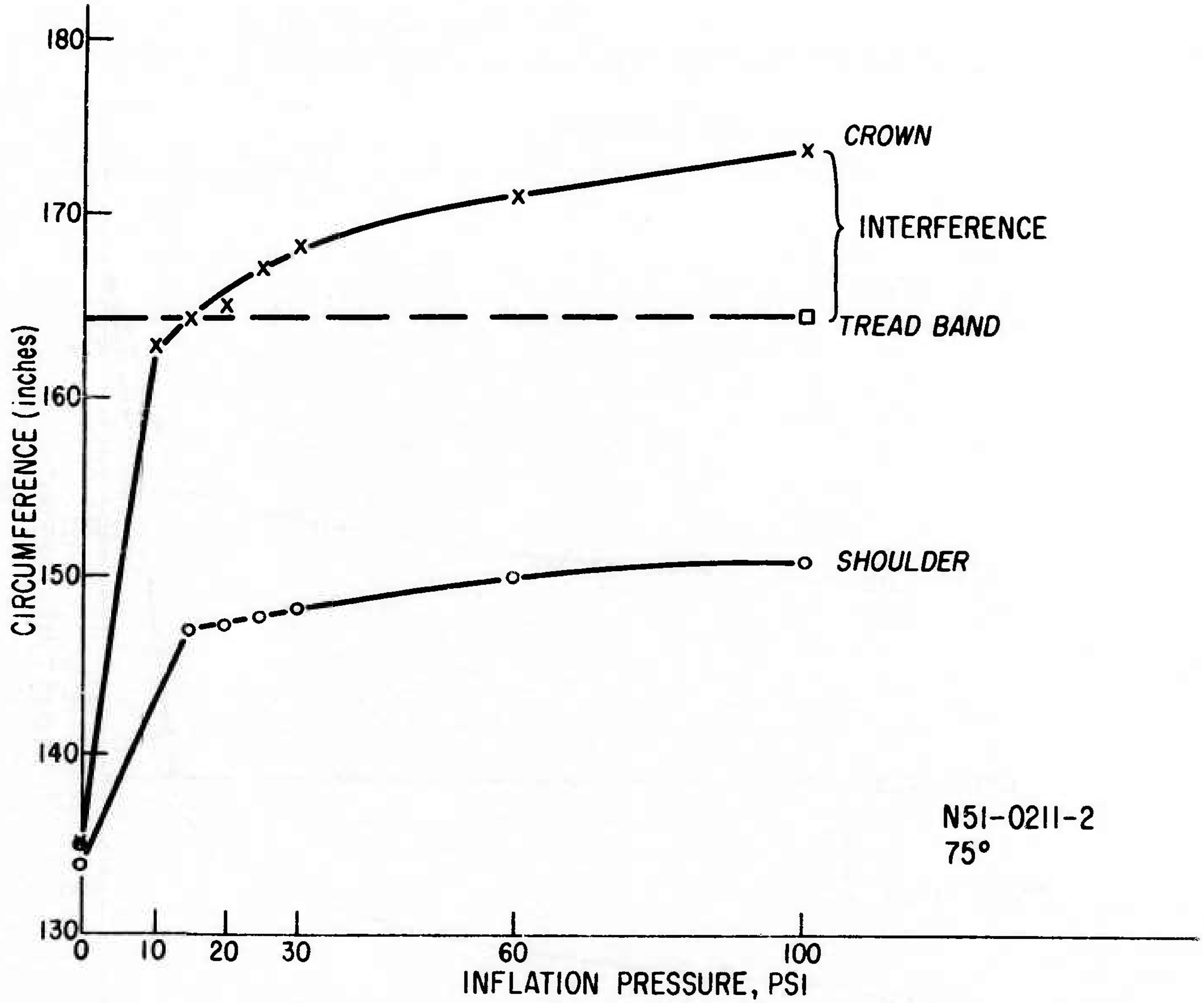

Figure 5. CIRCUMFERENCE of 72° CARCASS WITHOUT ITS BELT as a FUNCTION of INFLATION PRESSURE

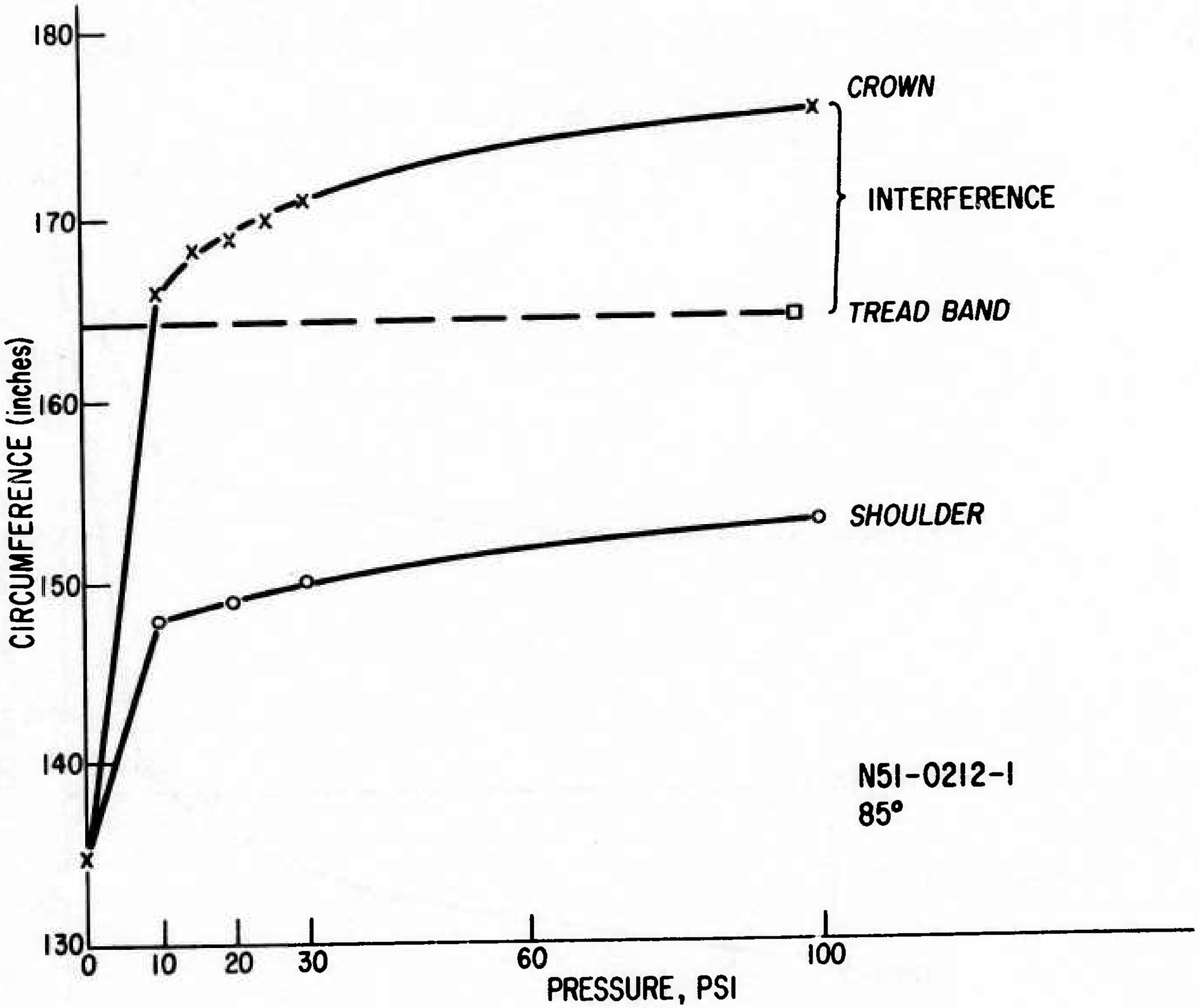

Figure 6. CIRCUMFERENCE of 85° CARCASS WITHOUT ITS BELT as a FUNCTION of INFLATION PRESSURE

Table VI compares the dimensions of the same three carcasses when assembled with a tread band and inflated to 125 psi. No significant differences are evident among the three tires and all three conform to MIL-T-5041F dimensional requirements.

Table VI. Diameter and Section Width of 20.00-20 Bias Carcass Replaceable Tread Tires at 125 psi.

Tire No.	Bias Angle	Crown Diameter	Section Width
N51-0210	55°	54.75 inches	20.10 inches
N51-0211	72°	54.70	19.63
N51-0212	85°	54.90	19.90
MIL-T-5041		56.00/54.30	20.10/19.20

2.2.2 Derailment Tests

Dynamometer tests were conducted on the 85°, 72°, and 55° carcasses assembled with a rayon cord tread band to evaluate derailment. Conditions of the test were:

Inflation Pressure	125 psi
Load	46,500 lbs.
Speed	25 mph
Max. Yaw Angle	± 6°
Camber Angle	0°
Rolling Time	30 seconds

Results of these tests showed that the 55° carcass (N51-0210) derailed; both the 72° carcass (N51-0211) and the 85° carcass (N51-0212) did not derail. Subsequently the 72° carcass was tested at a ± 10° yaw angle. Even at this more severe condition the tread band did not derail. See Table VII.

Because of the encouraging results of these tests the same three carcasses and two tread bands were shipped to AFFDL for further derailment testing. All tests were conducted at 5 mph and 46,500 lbs. load. The rated inflation pressure of 125 psi was adjusted to 147.5 psi for road wheel curvature. Yaw and camber conditions were as follows:

Yaw	Camber
0 to + 10°	0°
0 to - 10°	0°
0	0 to + 10°
0	0 to - 10°
0 to + 10°	0 to + 10°
0 to + 10°	0 to - 10°
0 to - 10°	0 to + 10°
0 to - 10°	0 to - 10°

Derailment tests were run at 147.5, 132.5, 117.5, 102.5 and 87.5 psi at each yaw and camber angle in order to determine the point of derailment. No tread band derailment occurred under any of the test conditions on the 85° and 72° carcasses; the 55° carcass did derail however.

The results of both tests indicated that derailment, the item of major concern for the replaceable tread concept, appeared not to be a problem for the initial 20.00-20 size. Fabrication difficulties with the 85° carcass and derailment failures of the 55° carcass eliminated these two from further consideration. Consequently, the 72° cord angle was selected; the 64° carcass was added as a back-up.

Table VII. Derailment Test of the 20.00-20/26 PR Expandable Carcass-Replaceable Tread Tire.

Specification Number	Yaw Angle	Speed	Roll Time	Results
N51-0210-1 (55° carcass)	0	25 MPH	30 sec.	Tread band slippage 90°
R51-0213-1 tread band	+6°	25 MPH	30 sec.	Tread band derailment
N51-0211-2 (72° Carcass)	0°	25 MPH	30 sec.	No band slippage
R51-0213-1 tread band	+6°	25 MPH	30 sec.	No band slippage No derailment
	-6°	25 MPH	30 sec.	No band slippage No derailment
	-10°	25 MPH	30 sec.	No band slippage No derailment
N51-0212-1 (85° carcass)	0°	25 MPH	30 sec.	No band slippage
R51-0213-1 tread band	+6°	25 MPH	30 sec.	No band slippage No derailment
	-6°	25 MPH	30 sec.	No band slippage No derailment
	-10°	25 MPH	30 sec.	No band slippage No derailment
N51-0230-2 (64° carcass) B51-264-1 tread band	+6°	10 MPH	90 sec.	Derailment

Load 46,500 lbs., inflation 125 psi, 20.00-20 wheel

2.2.3 Hydrostatic Burst Tests

Hydrostatic burst tests were conducted on one rayon and two Fiber "B" tread bands using both 72° and 85° carcasses. The rayon band failed at 480 psi; mode of failure was a circumferential split. This was the first indication that it would eventually become necessary to depart from the basic tread band design of the 6.00-6 size by adding one layer of cords in the lateral direction.

One of the considerations during the early stages of tread band design was material. Ten plies of rayon made a heavy tread band. We felt that it would behoove us to reduce its weight by reducing the number of plies which was made possible by the use of a stronger cord. Fiber "B" was selected. Several 6 ply belt bands were constructed and cured. The first such tread band was constructed on a slightly undersize mandrel. During cure the cords at the crown tended to shift toward the edges. The result was a tread band of non-uniform thickness with the crown having far fewer cords than the edges. When burst, this tread band failed at 260 psi; mode of failure was circumferential splitting. On the subsequent tread band the mandrel diameter was increased sufficiently to produce a satisfactory tread band, which burst at 540 psi, well above the required 460 psi. Results of these burst tests are summarized in Table VIII.

Table VIII. Hydrostatic Burst Data for the 20.00-20/26 PR Expandable Carcass - Replaceable Tread Tire

Specification Number	Burst Pressure*	
N51-0212-2 Carcass, 85° R51-0213-4 Belt Band, Rayon	480 psi	Belt band failure circumferential split carcass intact
N51-0211-2 Carcass, 72° R51-0213-3 Belt Band, Fiber B	** 260 psi	Belt band failure circumferential split carcass intact
N51-0211-2 Carcass, 72° R51-0213-5 Belt Band, Fiber B	540 psi	Tensile failure in belt band then carcass rupture

* Required minimum is 460 psi as specified on USAF drawing 65D1542.

** Examinaton of tread band indicated insufficient cords in the crown caused by the use of too small a mandrel diameter during construction. This defect was eliminated on subsequent tread bands.

2.2.4 Dynamometer Tests

Armed with the encouraging results of the derailment tests we embarked on a program to evaluate performance of the 20.00-20 replaceable tread tire under taxi, take-off and landing conditions. The ultimate goal was to pass 125 taxi - take-off cycles and 125 landing - taxi cycles as specified on USAF drawing 65-D-1542. Loads as high as 46,500 pounds and speeds of 200 mph are specified. Table IX lists all the dynamometer tests which were conducted. Seven carcass cord angles, two crown contours (flat and 18.6 inch radius) and many construction improvements were incorporated into these carcasses. Tread band improvements included cord material, number of plies, location of transverse ply, inside contour, inside diameter, width and other construction features. All of these improvements were aimed at resolving manufacturing as well as performance difficulties. The manufacturing problems were discussed previously. The performance problems may be categorized as follows: (1) belt splitting, (2) chafing, (3) tread band breakage, and (4) ply separations.

2.2.4.1 Tread band splitting

The early dynamometer tests substantiated the results of the burst tests, that tread bands were splitting. We concluded that some lateral reinforcement was needed and single ply with cords oriented 90° was selected. The question was where to locate it. Three locations were considered: the outermost ply, the middle ply, and the innermost ply. From a bending standpoint the middle ply was perhaps the best location. In order to minimize any extensional incompatibility then either the innermost ply or the outermost ply was reasoned to be best. Results of the dynamometer tests were inconclusive to show superiority of one location over the others. However, it is important to note that the addition of the 90° ply did resolve the tread band splitting problem.

2.2.4.2 Chafing

It was at this stage of the program that the chafing problem was discovered. During one of the first dynamometer tests of the redesigned tread band with the 90° cords at the innermost ply, the carcass exploded during the 10th taxi-take-off cycle. Examination of the carcass disclosed the failure region to be in the shoulder area as shown in Figures 7 and 8. Both shoulders of the carcass had two plies of cord abraded away around the entire circumference. The inside of the tread band disclosed damage at both edges

Table IX. Summary of Dynamometer Tests* on the 20.00-20/26 PR Expandable Carcass-Replaceable Tread Tire.

Date	Carcass	Tread Band	Remarks
Pre-June	72°, 64°, 55°	10 Ply Rayon 0°	Split Belt Burst Carcass
6/12/73	N51-0211-9	B51-B-0213-5 6 Plies Fiber "B" 0° 1 Ply at 90° Bonded to inside surface of previously cured belt	Adhesive Bond Failure Led to Split Belt and Burst Carcass
6/13/73	N51-0211-3 72° Cord Angle Revised Mold	B51-B-0257-1 Fiber B 90°-0°-0°-0°-0°-0°-0°-0°	Scrubbing of Belt Edges Wore thru 2 Plies of Cord on Carcass Causing Rupture 10 cycles
7/17/73	N51-0211-10 72° Cord Angle	B51-B-263-1 Fiber B 0°-0°-0°-0°-90°-0°-0°-0°	Tensile Failure of Tread Band Carcass Undamaged 3 cycles
7/17/73	N51-0211-10 72°	B51-B-257-2 Fiber B 90°0°-0°-0°-0°-0°-0°-0°	Scrubbing at Belt Edges, Carcass Rupture 6 cycles
7/18/73	N51-0230-2 64°	B51-B-264-1 Fiber B 0°-0°-90°-0°-0°	Adhesion of Belt to Carcass-Test Stopped, Scrubbing at Shoulder 4 taxi warm-ups
7/18/73	N51-02302 64°	B51-B-266-1 70°-70°-0°-0°-0°-0°	Shear Failure of 70° Plies in Belt 4 taxi warm-ups
10/1/73	N51-B-0231 A-5 74° Cord Angle	B51-B-275-1 0°-0°-0°-0°-90° Small Inside Dia.	Loss of adhesion at 90° Ply, Tread Came Off, 4 taxi warm-ups
10/1/73	N51-B-231 A-5 74°	B51-B-276-1 0°-0°-0°-0°-90° Flat Contour	Scrubbing at Belt Edges 8 cycles
10/2/73	N51-B-0230 A-1 67°	BW51-B-274-1 0°-0°-90°-0°-0° Steel Wire at Edges	Scrubbing at Belt Edges 4 taxi warm-ups
10/2/73	N51-B-0230 A-1 67°	BW51-B-268-1 0°-0°-0°-0°-90° Elastic Band	Scrubbing at Belt Edges 1 cycle
4/1/74	N51-B-0231 B-5	B51-B-268-1 4 ply Small dia.*, narrow	Scrubbing at Belt Edges 1 cycle
4/1/74	N51-B-0231 C-4	B51-B-298-2 4 ply Small dia.*, narrow	Tread Came Off - No Scrubbing 1 cycle
5/20/74	N51-B-0231 A-2	B51-B-305 6 ply Small dia.*, narrow	Tensile Failure of Tread Band - No Scrubbing 2 cycles
5/23/73	N51-B-0231 C-4 N51-B-0212-1	B51-B-308 6 ply Small dia.*, narrow	Cord Separation at Belt Edges, Test Stopped, No Scrubbing, 6 taxi warm-ups
5/21/74	N51-B-0231 C-3	B51-B-306 7 Ply Small dia.*, narrow	Threw Tread, No Scrubbing 1 cycle

* All tests were Taxi-Take-Off per USAF drawing 65-D-1542.
** An Undersized Belt.

Figure 7. Photograph of Carcass After Rupture Caused by Chafing.

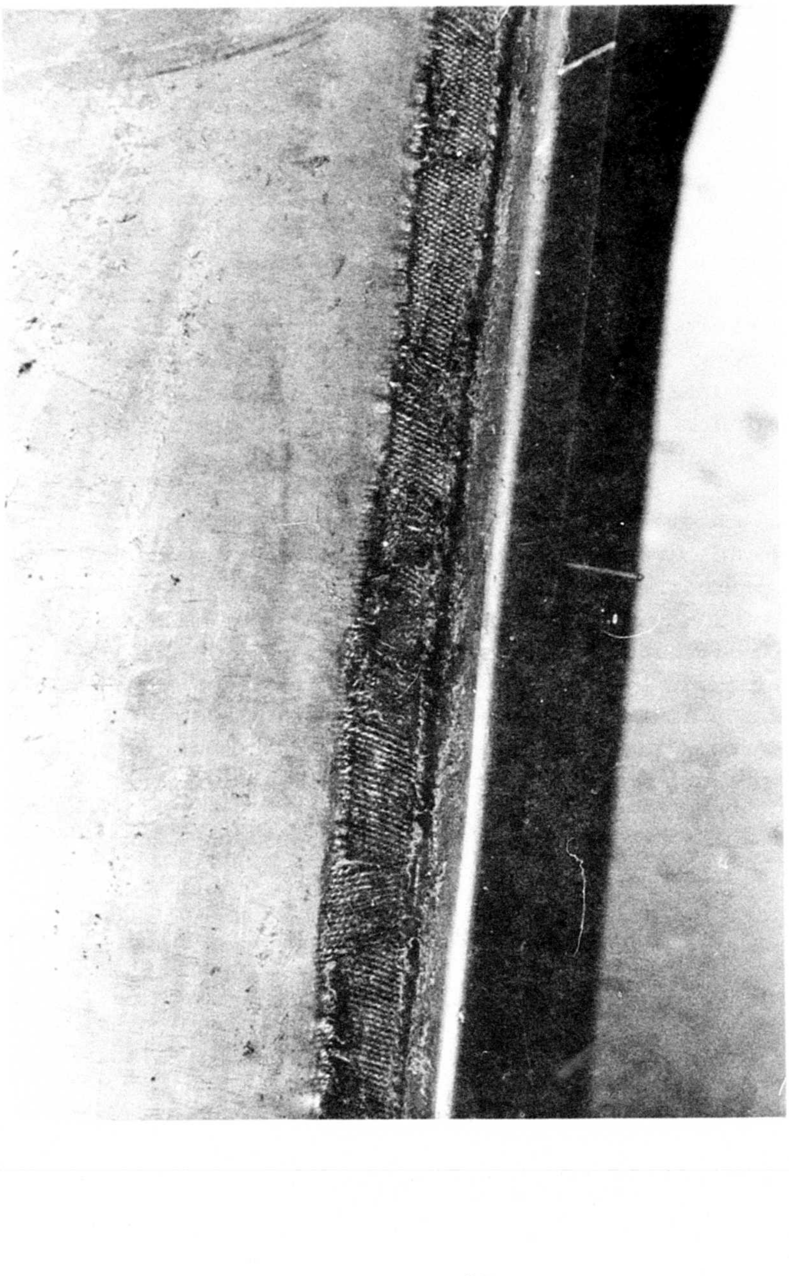

Figure 8. Closeup Photograph of Carcass Cords Damaged by Chafing.

as seen in Figure 9. We concluded that the tread band was moving on the carcass, probably when going through the footprint. The outside surface of the tread band also showed severe abrasion at both edges. See Figure 10. At this point we did not know whether the abrasion on the outside of the tread band was related to the chafing at the interface of the carcass and tread band.

Thus a program of build, test, analyze, and change was initiated. The carcass and tread band design changes described in 2.2.4 above were tried but were not effective in resolving the chafing or even in reducing it. Tissue paper tests which are described in 2.2.5 indicated a relative sliding motion was occurring between carcass and tread band, but at the belt edges only, not at the center. Interface pressures were extremely low at the belt edges. We hypothesized that the chafing was caused by a reciprocating sliding motion between belt and carcass, limited to the should area and produced by insufficient interference. Consequently, we manufactured a new belt mold to produce a tread band four inches smaller in diameter and approximately one inch narrower.

A total of eight such modified tread bands were constructed and cured. Subsequent dynamometer tests resulted in premature failures during the first or second taxi - take-off cycle. These failures were in belt breakage and thrown tread rubber. There was no evidence of chafing at the carcass-tread band interface or scuffing on the outside of the belt; we considered this to be a marked improvement over previous tread bands which had shown severe chafing and scuffing after one taxi - take-off. See Figures 11 and 12.

Figure 9. Photograph of Inside of 20.00-20/26 PR Tread Band Showing the Chafing Damage Along One Edge.

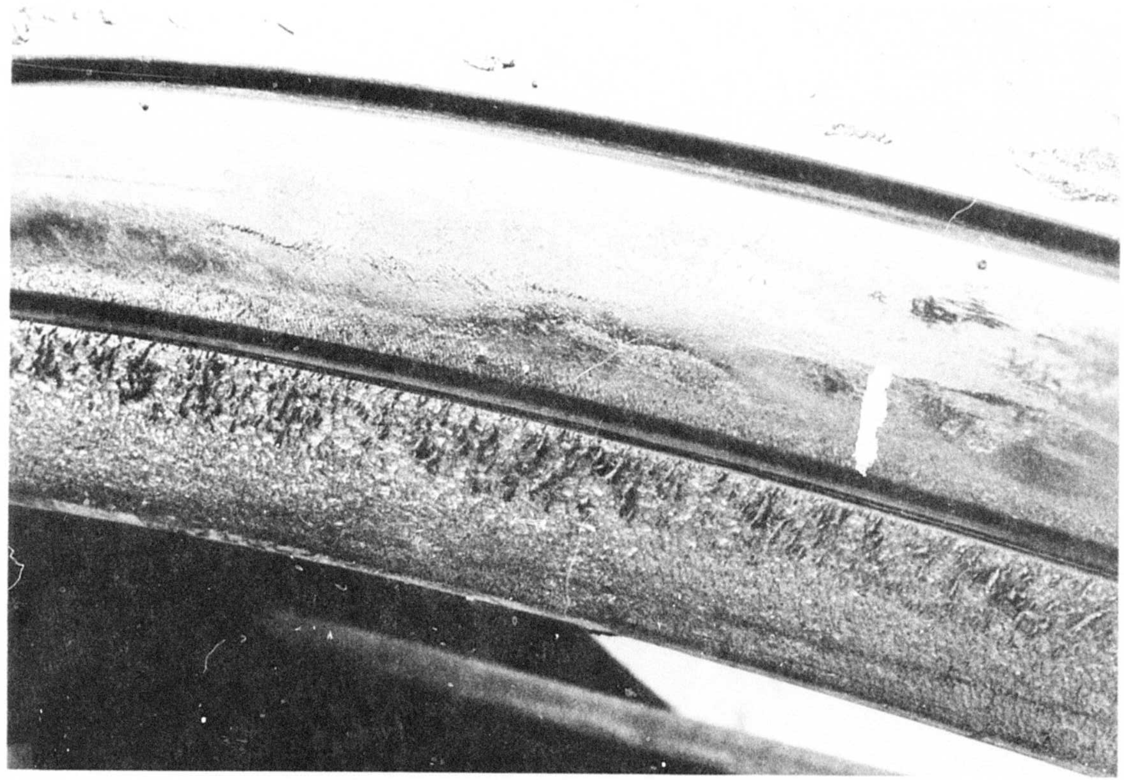

Figure 10. Photograph of Outside of 20.00-20/26 PR Tread Band Showing Abrasion Along One Edge.

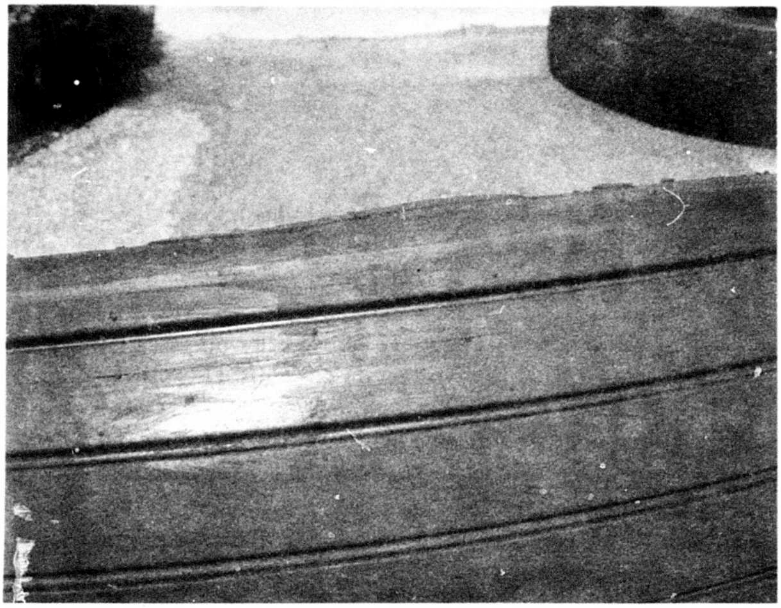

Figure 11. Photograph of Outside of Modified Tread Band After Dynamometer Test Showing No Abrasion.

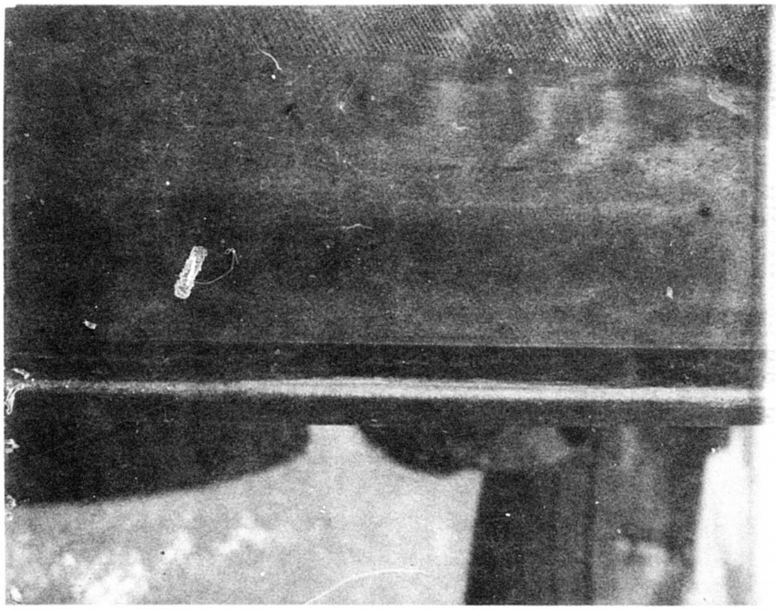

Figure 12. Photograph of Carcass Shoulder Area After Dynamometer Test Showing No Chafing.

2.2.4.3 Tread Band Breaks

One of the failure modes of the newly modified smaller and narrower tread band was cord breaks, See Figure 13. Observations made throughout the test and prior to gross failure showed many small, local failures were occurring at the edges of the belt. As testing progressed, the existing local failures became more severe and new ones appeared around the circumference. Continued testing apparently weakened the belt sufficiently to cause gross failure. Figures 14 and 15 show additional views of the failed belt. Similar observations were made at AFFDL by the project engineer on a modified 20.00-20 replaceable tread band. He reported, "Examination of the primary failure shows that the cord ends are highly frayed at the edges of the belt with a considerable mass of cord debris deposited between the 0 and 90 degree plies. The cords are less frayed as one moves toward the belt center and seem to have a much cleaner break. This suggests that the failure initiated at the belt edges and progressed toward the center at a fairly low rate, until the belt was critically weakened. This conclusion is born out by small failures which were initiated at two other points on the tread belt edges.". Figures 16 and 17 are photographs supplied by the AFFDL project engineer of the failures.

2.2.4.4 Ply Separations

The other failure mode of the newly modified, smaller and narrower tread band was loss of tread rubber. Separation was observed to occur in the plane between the ply cords as indicated by Figure 18.

In previous tests with the original tread band, ply separation was also observed. When transverse plies were incorporated into the belt, adjacent to the tread and adjacent to the liner, separation also occurred as shown in Figures 19 and 20. This failure mode may also initiate at the edges of the belt.

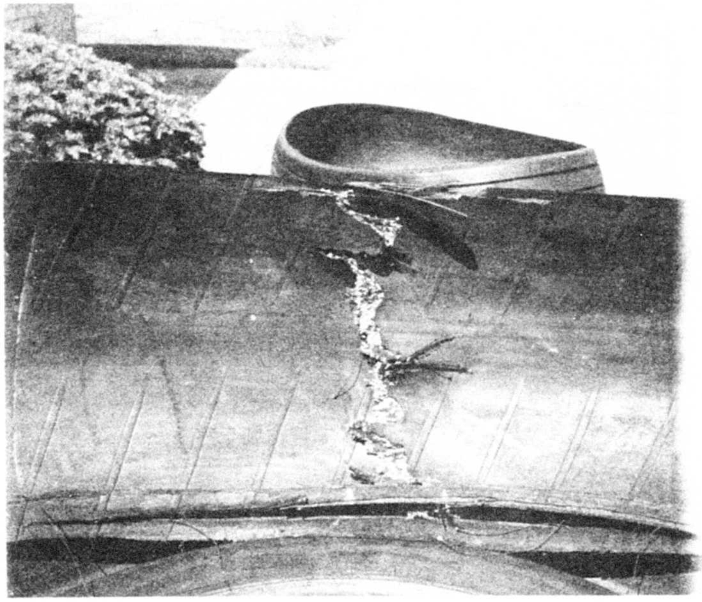

Figure 13. Photograph of a Tread Band Break in a Modified Tread Band.

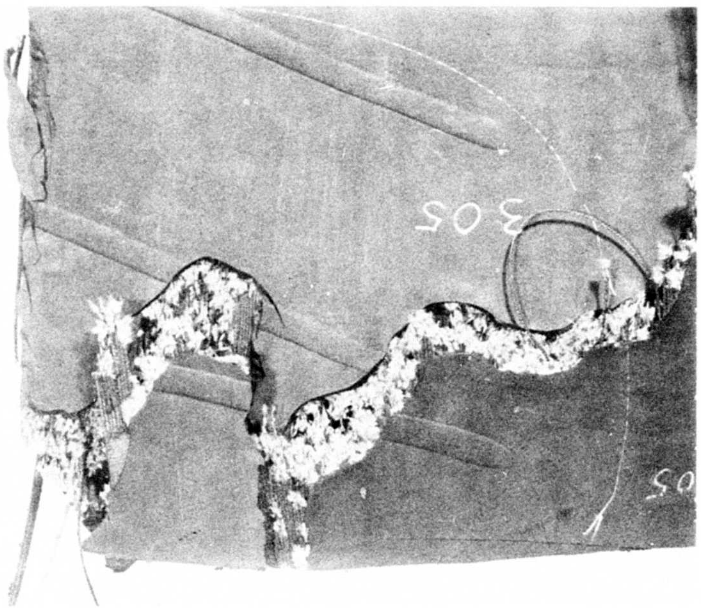

Figure 14. Closeup Photograph of Tensile Failure in a Modified Tread Band.

Figure 15. Closeup Photograph of a Cross-Section in a Modified Tread Band After Tensile Failure.

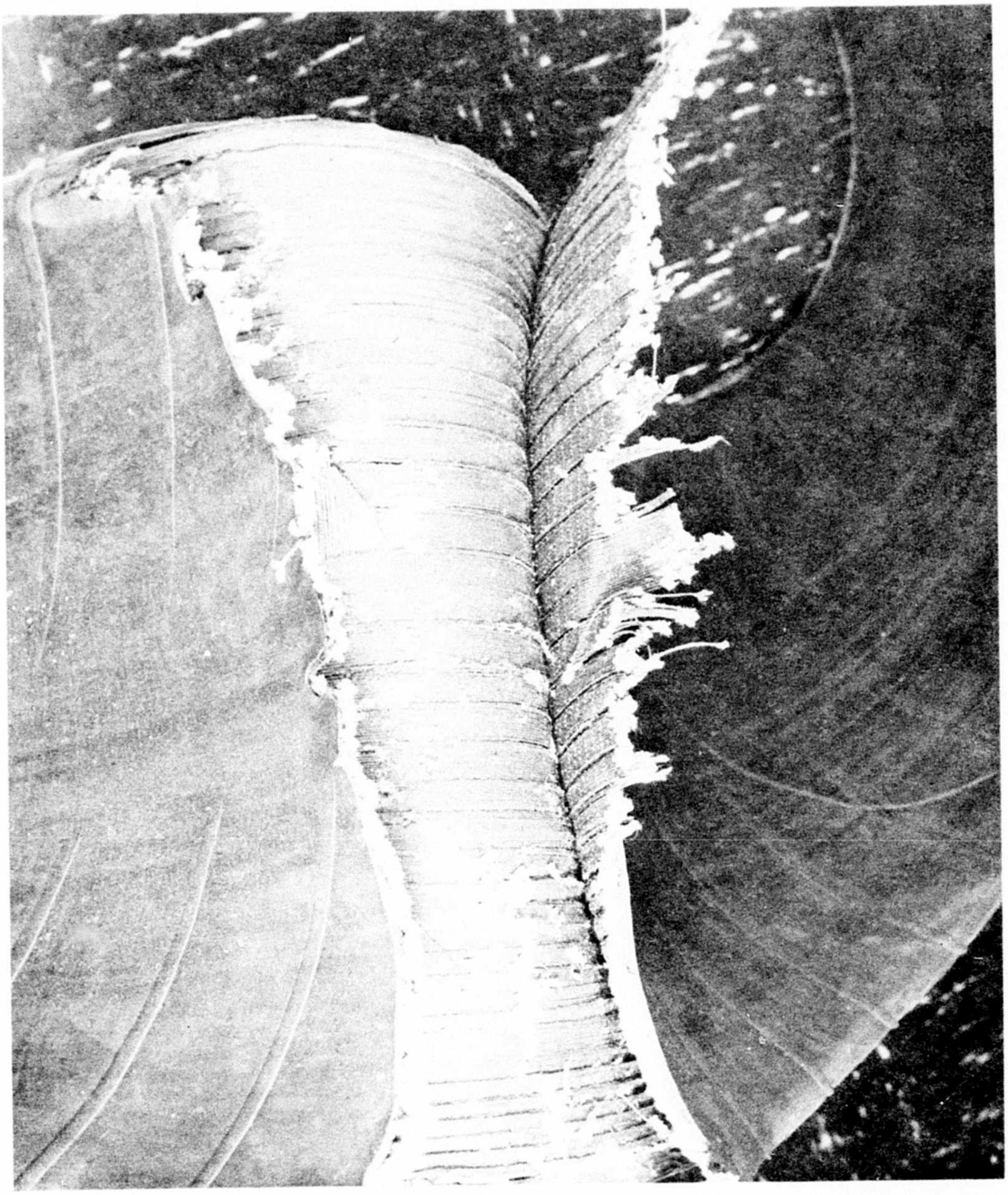

Figure 16. AFFDL Photograph of the Gross Failure of a Modified 20.00-20 Replaceable Tread Band.

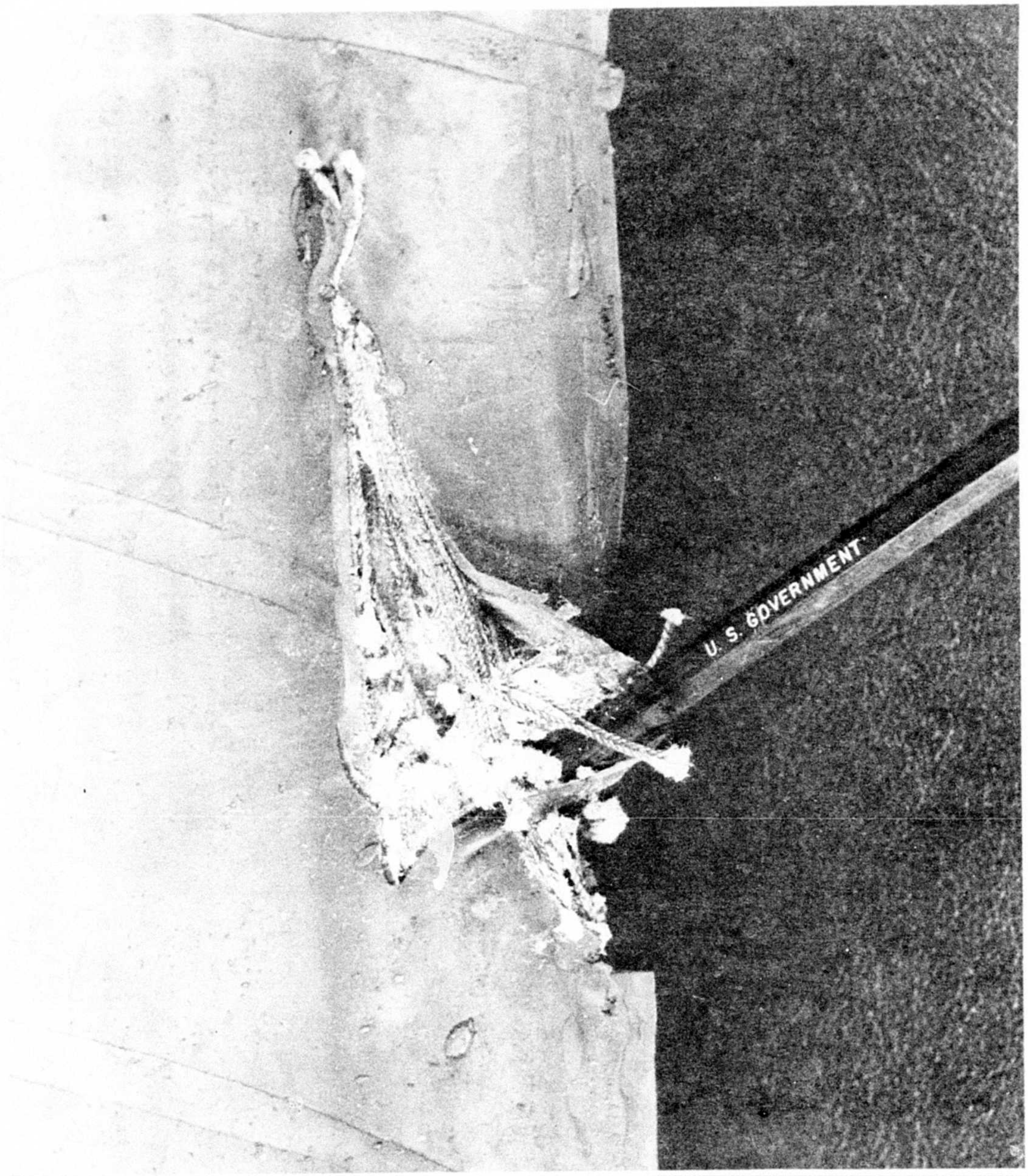

Figure 17. AFFDL Photograph of the Initiation of Failure at the Edge of a Modified 20.00-20 Replaceable Tread Band.

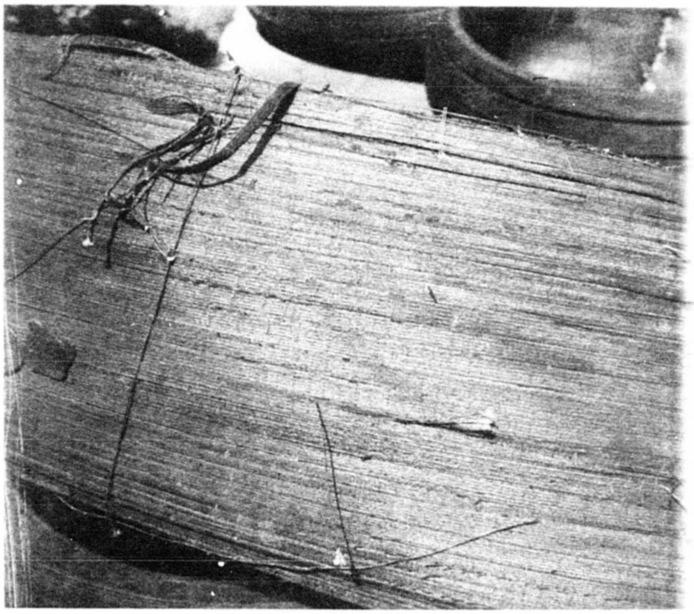

Figure 18. Photograph of a Modified 20.00-20 Tread Band After Failure by Loss of Tread Rubber.

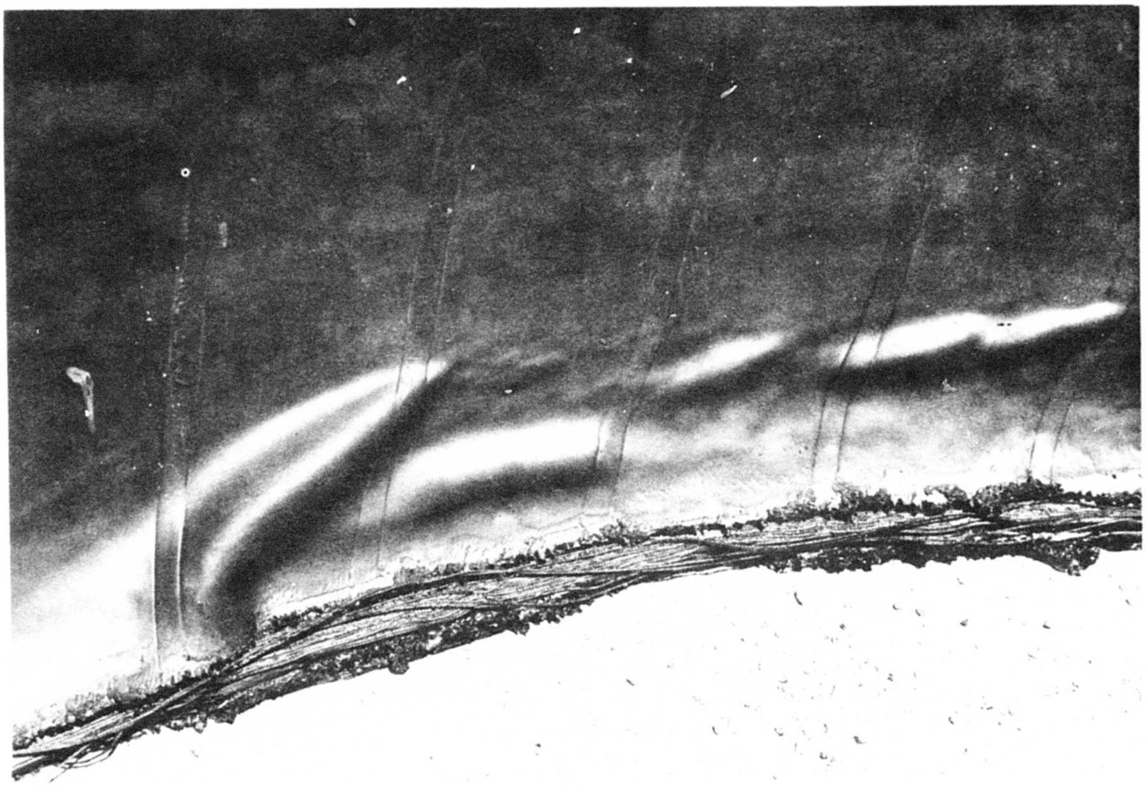

Figure 19. Photograph of a 20.00-20 Replaceable Tread Band which Failed by Ply Separation Adjacent to the Liner.

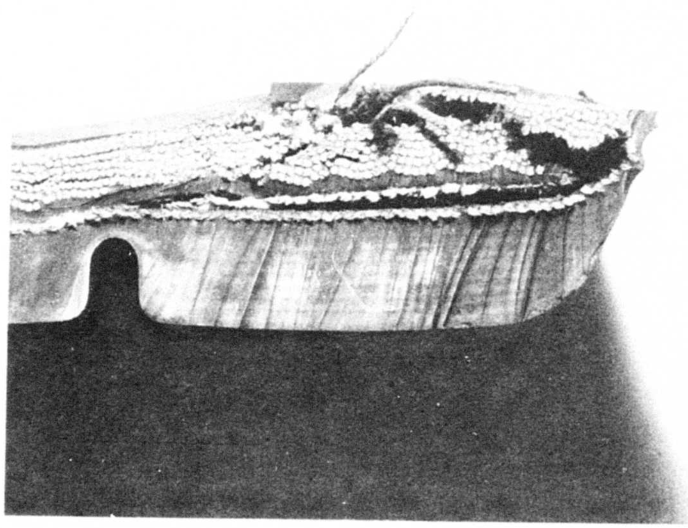

Figure 20. Photograph of a 20.00-20 Modified Replaceable Tread Band Showing Ply Separations at the Belt Edge.

2.2.5 Tissue Paper Studies

It was hypothesized that the chafing between tread band and carcass was the result of relative sliding at the interface of these two components. Furthermore, since no gross slippage was observed it was thought that the motion was oscillating. To confirm this hypothesis a series of tests was conducted on carcass N51-B-0230 A-1 and tread band B51-B-257-1. The carcass had one of its lips cut off to make the edge of the interface more visible. Screening tests were conducted to select a technique which would qualitatively show the motion and its direction. The following methods were tried:

a) A scratch gage consisting of sandpaper bonded to the inside surface of the tread band rubbing against a layer of paint on the outer surface of the carcass.

b) A scratch gage similar to (a) above in which brass SHIM stock was substituted for the paint.

c) Narrow strips of bond paper placed between carcass and tread band. It was hoped that relative sliding would tear or wrinkle the paper.

d) Tissue paper in narrow, one inch wide strips placed between carcass and tread band and oriented in both circumferential and axial directions.

e) Large 8-1/2 x 11 sheets of tissue paper placed between carcass and tread band.

The two tissue paper methods were selected on the basis of simplicity and reliability. We were interested in determining what the effects of inflation, loading and rolling were on the relative sliding. Consequently, the tissue paper was placed in position then the tire was:

a) inflated to 125 psi then deflated.
b) inflated to 147 psi and loaded to 46,500 lbs., then deflated.
c) inflated to 147 psi, loaded to 46,500 lbs. and rolled 5 cycles, retracted then deflated.

Examination of the tissue paper results shown in Figures 21 through 24 disclosed the following:

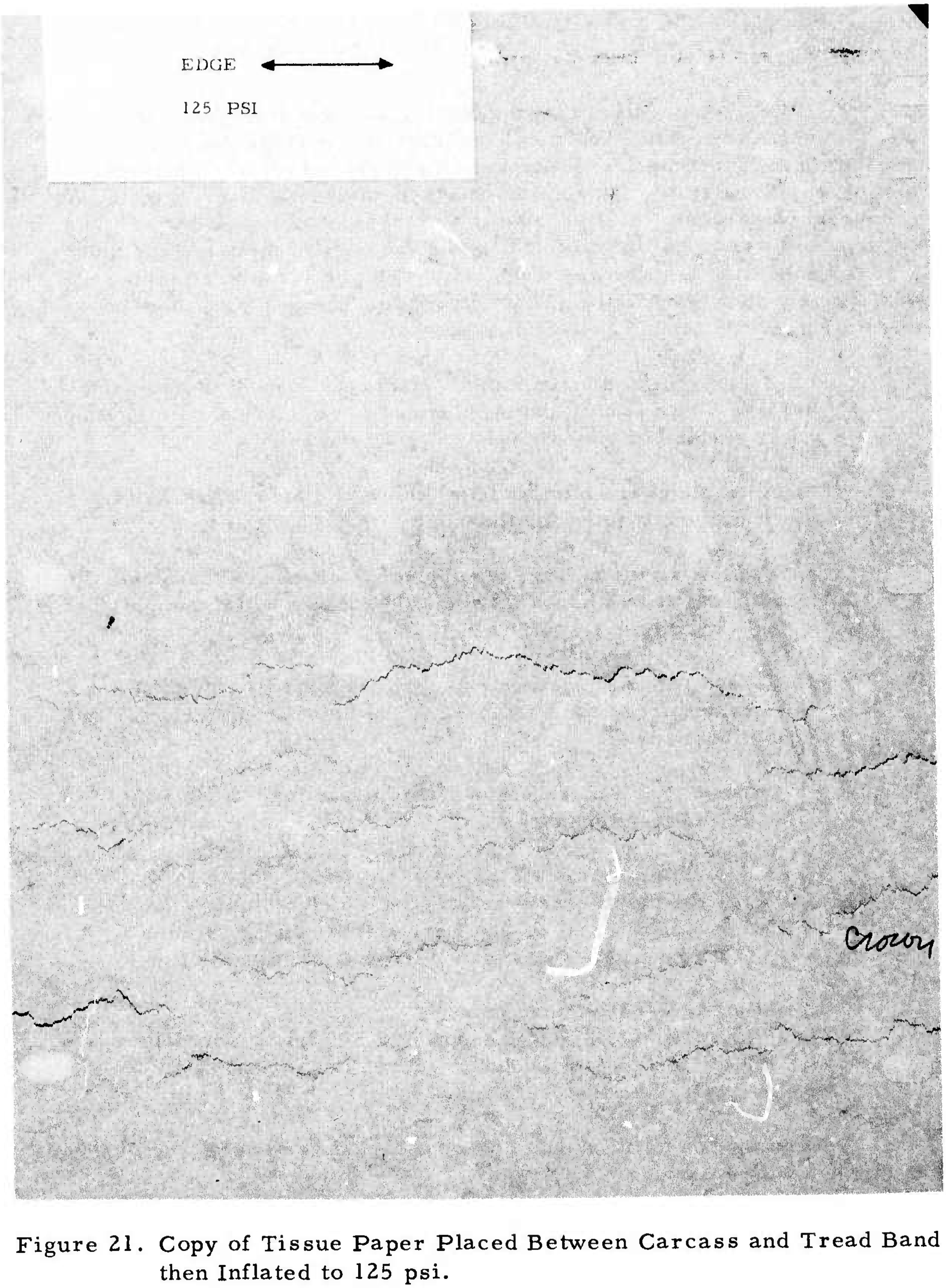

Figure 21. Copy of Tissue Paper Placed Between Carcass and Tread Band then Inflated to 125 psi.

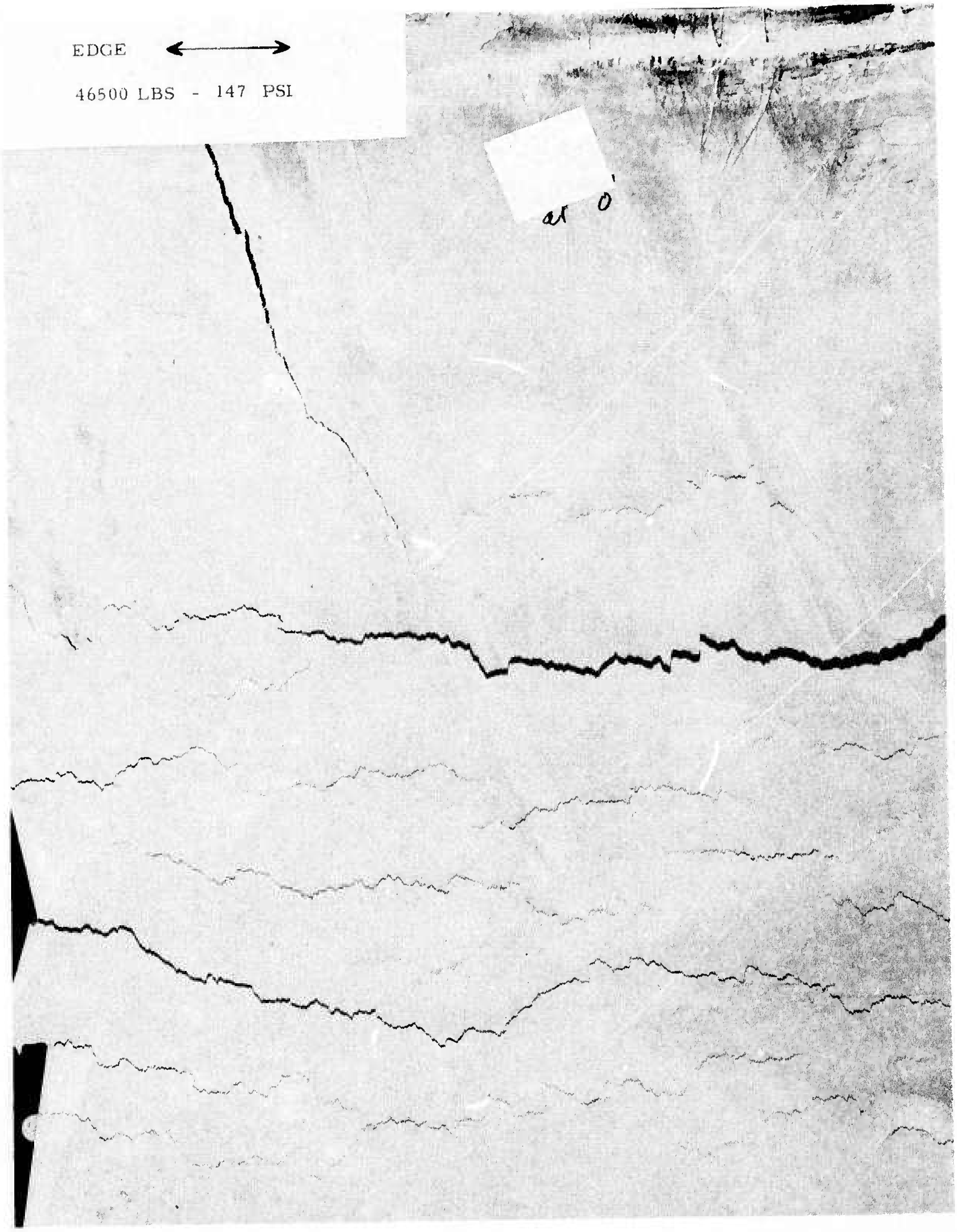

Figure 22. Copy of Tissue Paper Placed Between Carcass and Tread Band, Inflated to 147 psi and Loaded to 46,500 Pounds. Tissue Directly Under Load.

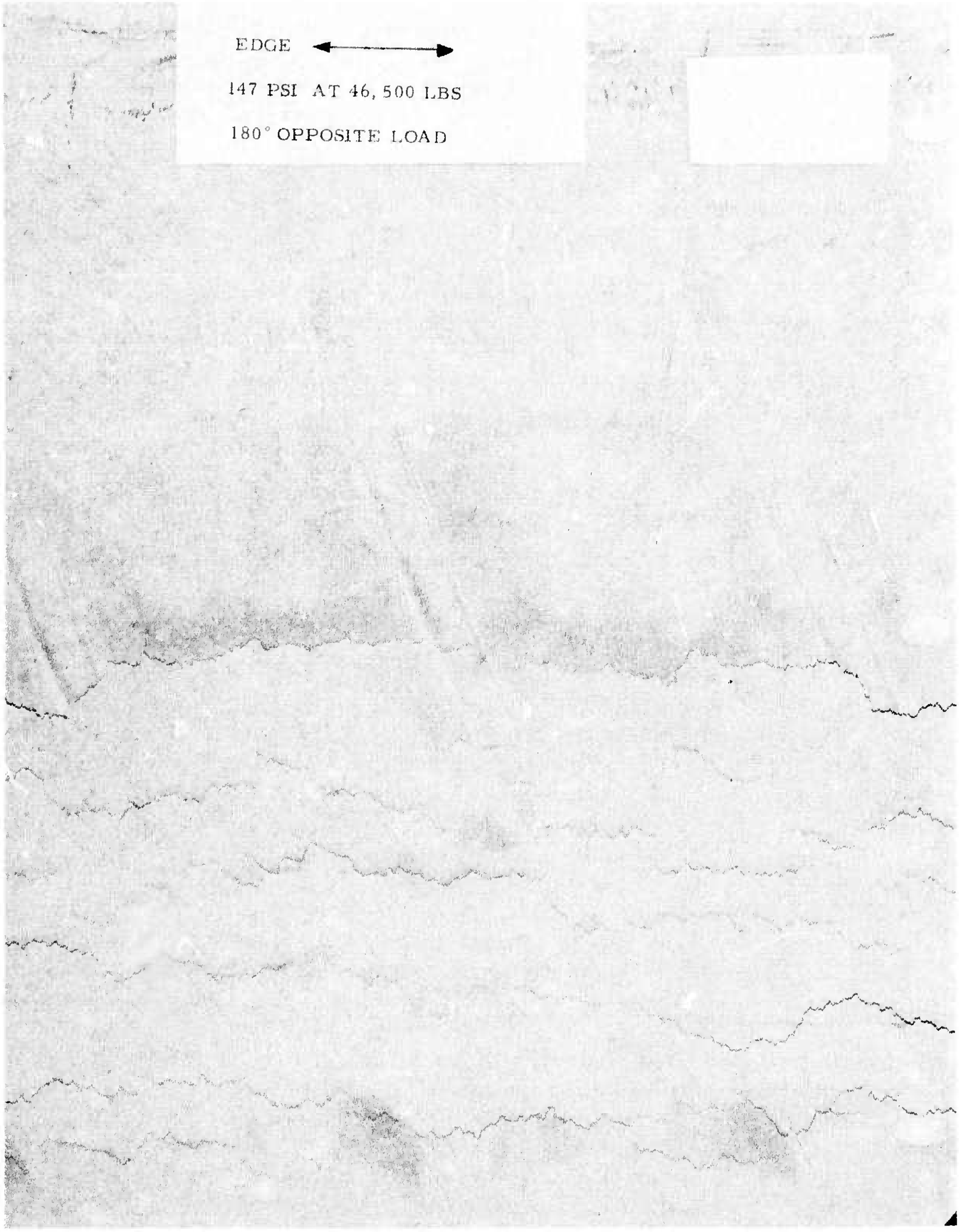

Figure 23. Copy of Tissue Paper Placed Between Carcass and Tread Band, Inflated to 147 psi and Loaded to 46, 500 Pounds. Tissue 180° Opposite Load.

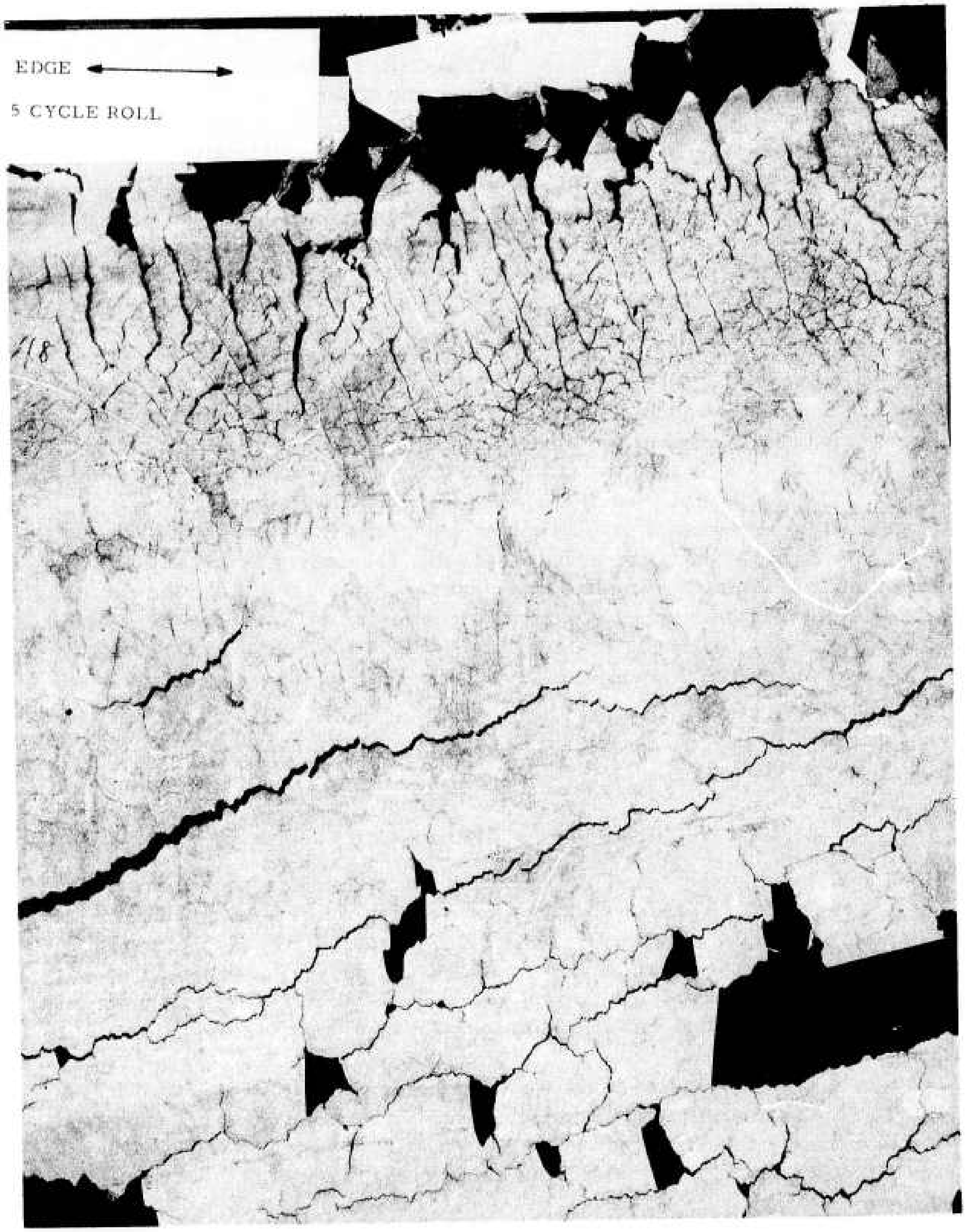

Figure 24. Copy of Tissue Paper Placed Between Carcass and Tread Band, Inflated to 147 psi, Loaded to 46,500 Pounds and Rolled through Five Cycles.

1) Inflating the tire caused a very slight degree of sliding between carcass and tread. This sliding was limited to the crown only and was in the axial direction.

2) Loading the tire caused no additional sliding either in the footprint region or directly opposite. No other locations were examined.

3) Rolling the tire produced sliding at the interface in the shoulder region (edge of belt). This sliding was circumferential in direction.

4) A gap 3 to 4 inches deep was observed between carcass and tread band at 125 psi. This gap closed up when the tire was left inflated for several minutes.

The next series of tests was conducted to answer the question, "Can chafing be reduced or eliminated by increasing the amount of interference between tread and carcass?" Five carcass-tread band combinations having a range of interferences was selected from the existing 6.00-6 tires. Tissue paper tests were conducted on these under rolling conditions. The following table lists these 6.00-6 replaceable tread tires by amount of interference, number 1 having the greatest interference:

Number	Serial Number	Type
1	637-372-5	Bias
2	N51-0056-7	Radial
3	657-372-8(new belt)	Bias
4	657-372-8(worn belt)	Bias
5	N51-0118-37	Radial

We were unable to correlate tissue paper results with magnitude of interference. However, the two radial carcasses did seem to show more sliding than did the bias carcasses.

A third series of tests was conducted on the 20.00-20 carcass N51-B-0231 A-2 and tread band B51-B-276-2. The purpose of these tests was to evaluate the effect of belt width on interface sliding. The tissue paper test was conducted under the same roll conditions described above on the

1) as molded tread band
2) one-inch trimmed from each edge
3) two-inches trimmed from each edge

The results of these tests disclosed no correlation between belt width and degree of interface sliding. We did observe, however, that gapping became greater as the belt became narrower.

2.2.6 High Speed Motion Pictures

These were taken to study the chafing phenomenon in slow motion. The following carcass - tread band combinations were filmed at 46,500 lbs. load, 147 psi inflation:

Carcass	Tread Band
N51-0211-9	B51-B-0213-5
N51-B-0231 C-4	B51-B-308
N51-B-0231 C-4	B51-257-2

Rolling speed was 30 mph, film speed was 500 frames per second. The camera was aimed to capture the tire going into the footprint, coming out of the footprint, 180° opposite the footprint, and an overhead view. A total of twelve, 100 ft. reels were shot. These will be delivered to the Air Force.

Examination of the films disclosed the following:

1) Circumferential sliding between carcass and tread band was observed on all of the above tires.
2) Circumferential sliding appears to occur in two local areas, entering the footprint and leaving the footprint. Actual footprint areas were obscured from the camera.
3) After unloading the tires all the lines on the carcass lined up with the lines on the tread band indicating no circumferential slip had occurred.
4) Circumferential sliding is a reciprocating motion and is to be differentiated from circumferential slip which is accumulative and non-reciprocating.
5) The undersized tread band (B51-B-308) had substantially less circumferential sliding than did the larger belt (B51-B-257-2).
6) Lateral sliding was not detected.

2.2.7 Additional Chafing Studies

These tests were conducted on the dynamometer to further study the causes of chafing between carcass and tread band. The N51-B-0231 C-4 carcass was selected along with a conventional size tread band, B51-B257-2, and an undersized belt, B51-B-308. Each belt was assembled with the carcass which was then inflated to 147 psi. The tire was then marked with equally spaced radial lines three inches apart. Each line was placed on the carcass and extended radially over the edge of tread band. At this point the tire was landed against the stationary road wheel; observations were made and photographs taken. See Figures 25 and 26.

The following observations were made:

1) Misalignment of the radial lines occurred only on each side of the footprint. The remainder of the tire, including the footprint zone, showed perfect alignment.
2) Measurement of the distance between lines indicated an elongation of the carcass. This elongation was adjacent to the footprint.
3) The tread band did not appear to elongate.
4) Elongation of the carcass was in the shoulder region only.
5) With the undersized tread band carcass elongation was substantially less than with the conventionally sized belt.

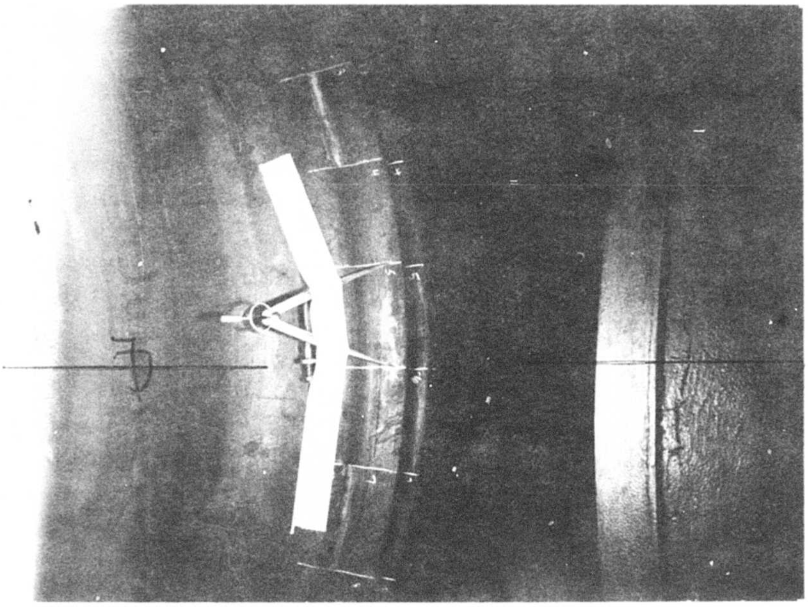

Figure 25. Photograph of a 20.00-20 Replaceable Tread Tire Marked with Equally Spaced Radial Lines.

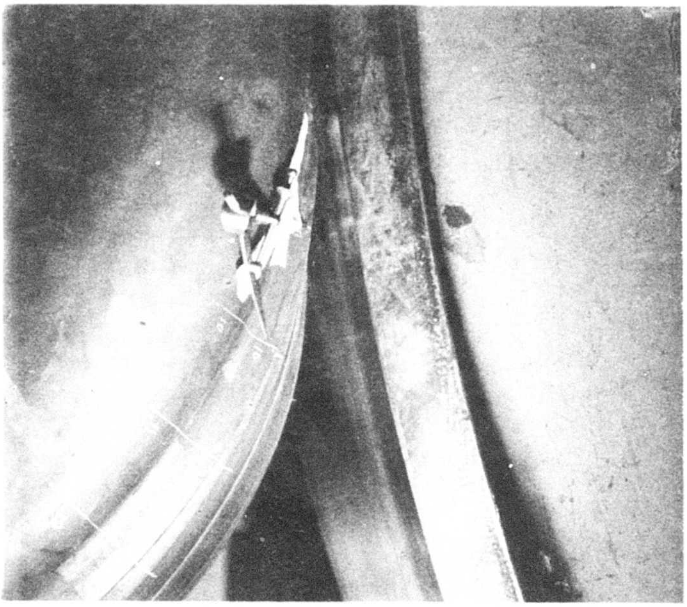

Figure 26. Photograph of 20.00-20 Replaceable Tread Tire under 46,500 Pounds Load Showing Carcass Elongation as Measured by Calipers.

2.2.8 Interface Pressure Measurements

Based on the success in Phase I a series of static measurements was taken to establish the pressure which the 20.00-20 carcass exerts against the inside of its tread band. The same miniature pressure transducers and measurement techniques described in AFFDL-TR-73-84 were used in this study. Measurements were taken under the following conditions:

a) Inflation pressure only at 100 and 147 psi.
b) At 147 psi inflation and 46,500 lbs load.

The above measurements were taken on the following carcass-tread band combinations:

Carcass		Tread Band
N51-0211-10	(72°)	B51-B-257-1
N51-B-0229-1	(55°)	B51-B-257-2
N51-B-0230-2	(64°)	B51-B-257-2
N51-0211-10	(72°)	B51-B-257-2
N51-0211-10	(72°)	B51-B-257-2 with elastic band
N51-B-0231 A-5	(74°)	B51-B-257-1
N51-B-0230 A-1	(68°)	B51-B-257-1
N51-B-0229 A-2	(62°)	B51-B-257-1
N51-B-0230 A-1	(68°)	BW51-B-274-1
N51-B-0230 A-1	(68°)	B51-B-275-1
N51-B-0230 A-1	(68°)	B51-B-276-1
N51-B-0231 A-2	(74°)	B51-B-276-2
N51-B-0231 A-2	(74°)	B51-B-276-2 (1 inch trimmed)
N51-B-0231 A-2	(74°)	B51-B-276-2 (2 inches trimmed)

These measurements were taken at various stages of the program in an attempt to correlate interface pressure with dynamometer performance and resolve the chafing problem.

Figures 27 through 31 show the interface pressure distribution for various carcass-tread band combinations at 100 psi inflation. When the chafing problem was first discovered we speculated that the belt band was actually too tight at the edges and thus was rubbing on the carcass. It was decided to reduce the interface pressure at the shoulders by recutting the tread band mold. The recut consisted of increasing the tread diameter at the edge only by 1/4 inch. The result was to reduce the interface pressure at the edges of the tread band as shown in Figure 27.

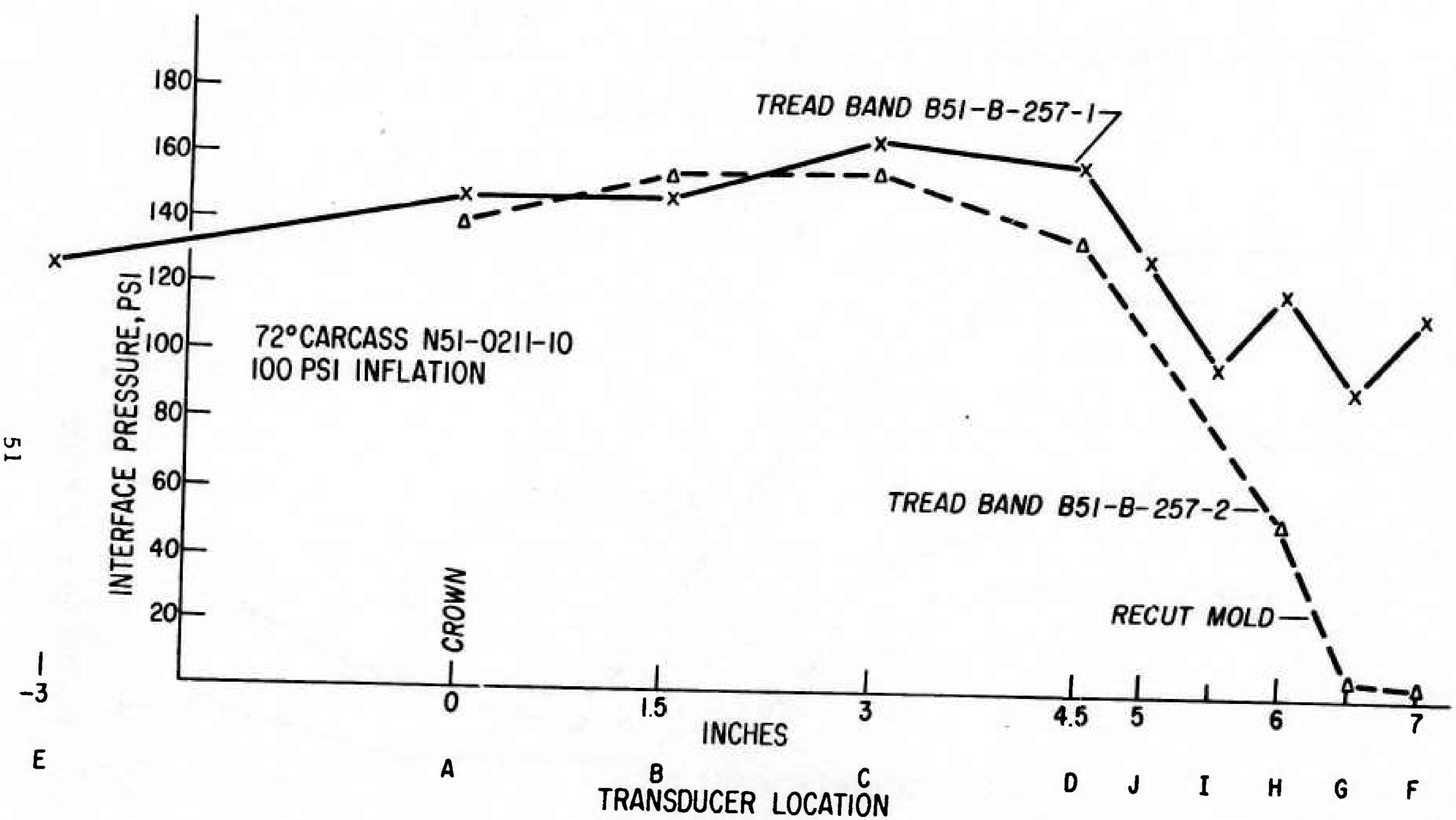

Figure 27. EFFECT of RECUTTING TREAD BAND MOLD on INTERFACE PRESSURE DISTRIBUTION of 20.00-20 REPLACEABLE TREAD TIRE

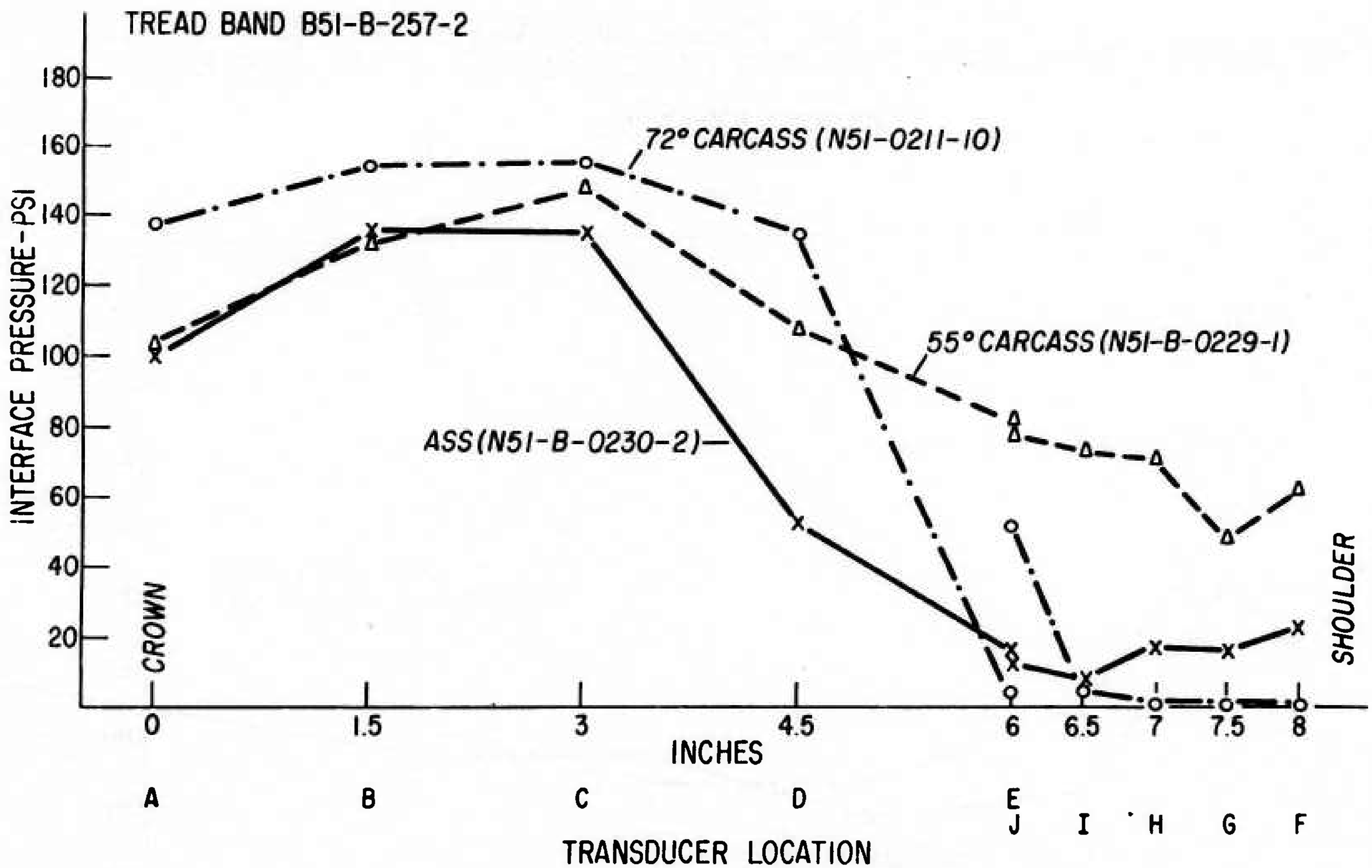

Figure 28. INTERFACE PRESSURE DISTRIBUTION for 20.00-20 REPLACEABLE TREAD TIRES at 100 PSI INFLATION

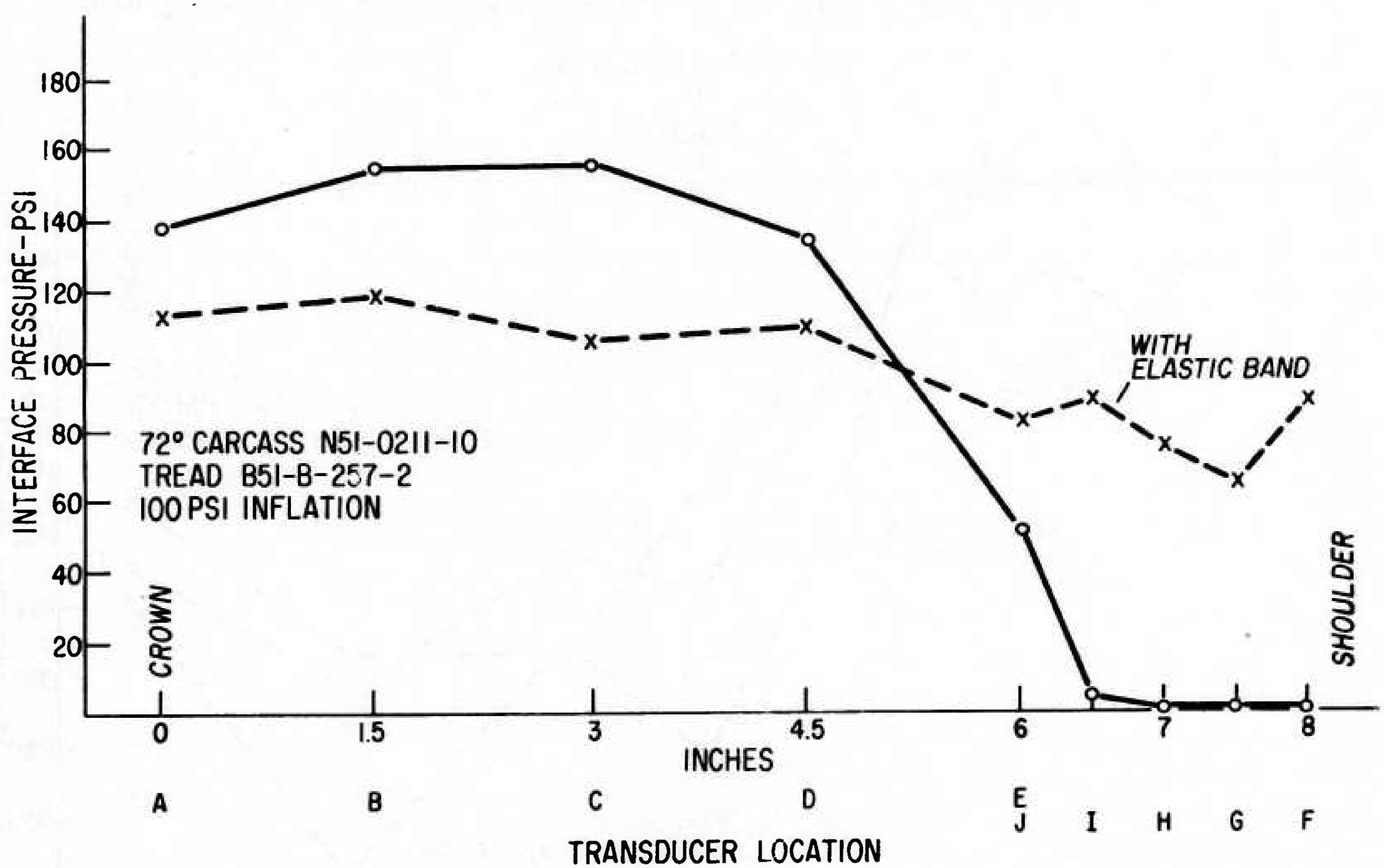

Figure 29. EFFECT of an ELASTIC BAND BETWEEN CARCASS and TREAD BAND on INTERFACE PRESSURE of a 20.00-20 REPLACEABLE TREAD TIRE

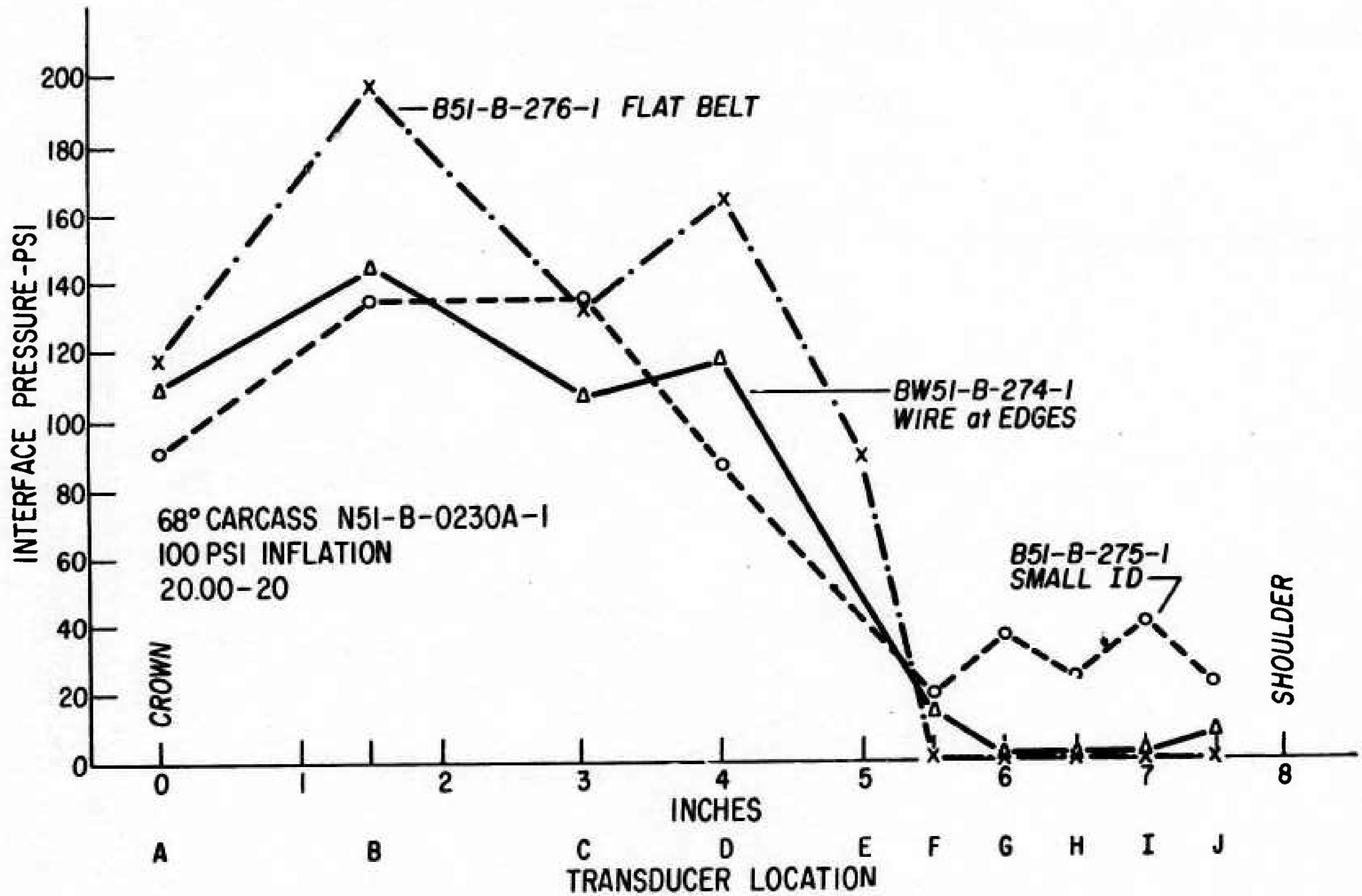

Figure 30. EFFECT of BELT CONSTRUCTION on INTERFACE PRESSURE

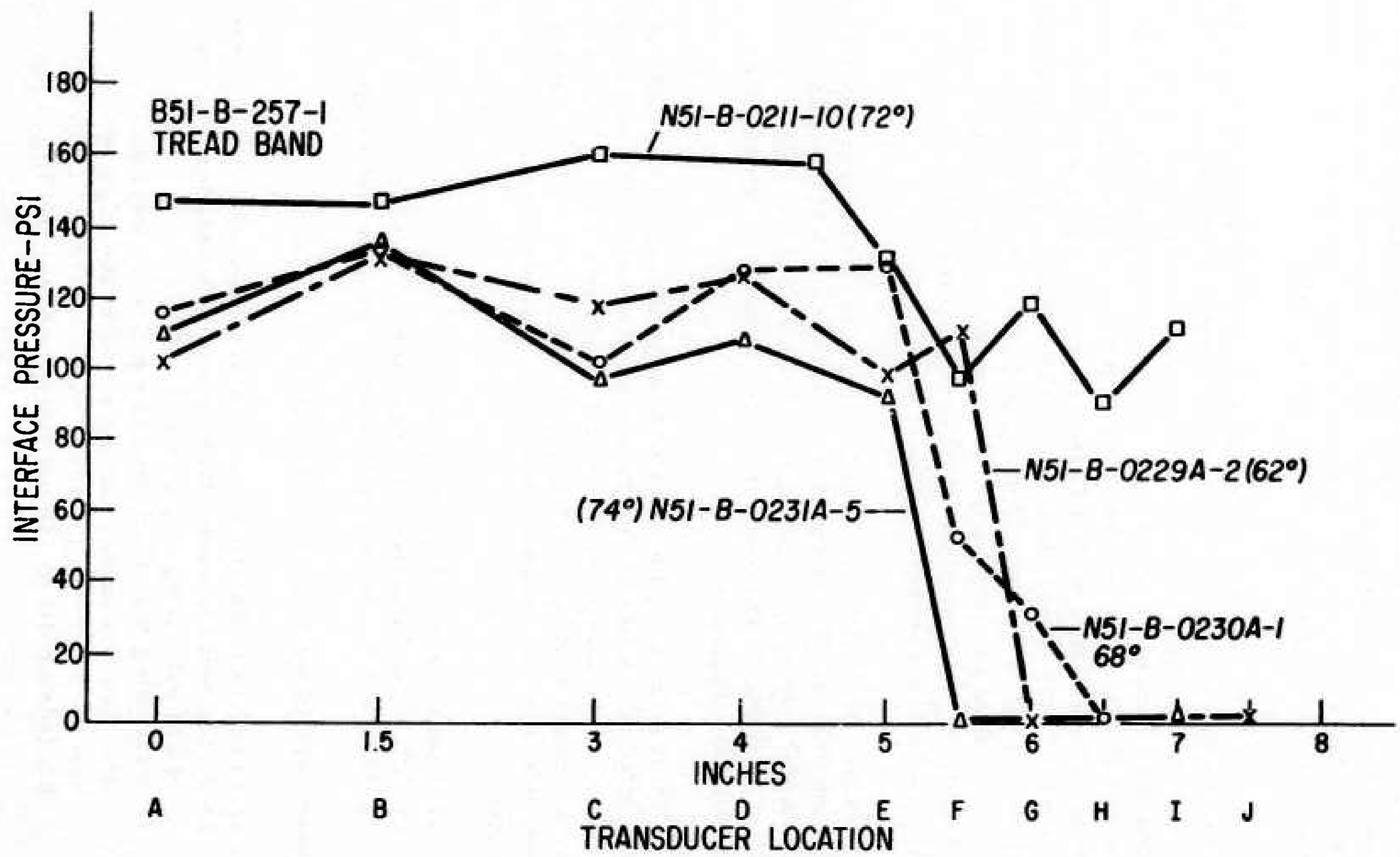

Figure 31. INTERFACE PRESSURE DISTRIBUTION for 20.00-20 REPLACEABLE TREAD TIRES at 100 PSI INFLATION

Figure 28 shows the effect of carcass angle on interface pressure. Both the 72° and 64° cracasses show very little interface pressure at the shoulder while the 55° carcass exerted approximately 50 psi. In the crown area, however, the 72° carcass produced the highest pressures. The most uniform distribution was on the 55° carcass.

In order to attain a higher interference fit between carcass and tread band many ideas were tried. One of these involved an elastic band placed between carcass and belt. Dynamometer tests showed no reduction in the chafing. Figure 29 shows that the interface pressure was substantially increased at the shoulder but reduced in the crown area. Other ideas which were tried included belts with a flatter contour (B51-B-276-1), a smaller diameter B51-B-275-1 and steel wire (BW51-B-274-1), at the edges to restrict movement at the shoulders. See Figure 30. Although none of these made any significant improvement in reducing chafing we were able to see that the tread band with the smallest inside diameter produced the greatest interface pressure.

Figure 31 shows how changes in carcass construction affected interface pressures. One of the initial carcasses, N51-B-0211-10, had the highest interface pressure both at the crown and at the edges. Although these construction changes were made to facilitate manufacturing, they reduced interface pressure.

Figures 32, 33, and 34 show how loading the 20.00-20 replaceable tread tire affected its interface pressure distribution. We were also interested in determining how belt width would affect interface pressure. This was accomplished by working with a single belt, and cutting it to narrower widths in two successive steps. Transducer measurements were taken:

a) With the as-molded tread band.
b) After one-inch was trimmed from each edge.
c) After a total of two inches were cut from each edge.

From these results we made the following conclusions:

1) Load has little effect on interface pressure at the crown.
2) At the belt edge interface pressure undergoes a range of 280 psi during any one roll cycle.
3) Narrowing the tread band has a direct effect on interface pressure. During a roll at the edge of belt the interface pressure range increases from 280 psi (wide belt) to 340 psi (intermediate) to 530 psi (narrow).

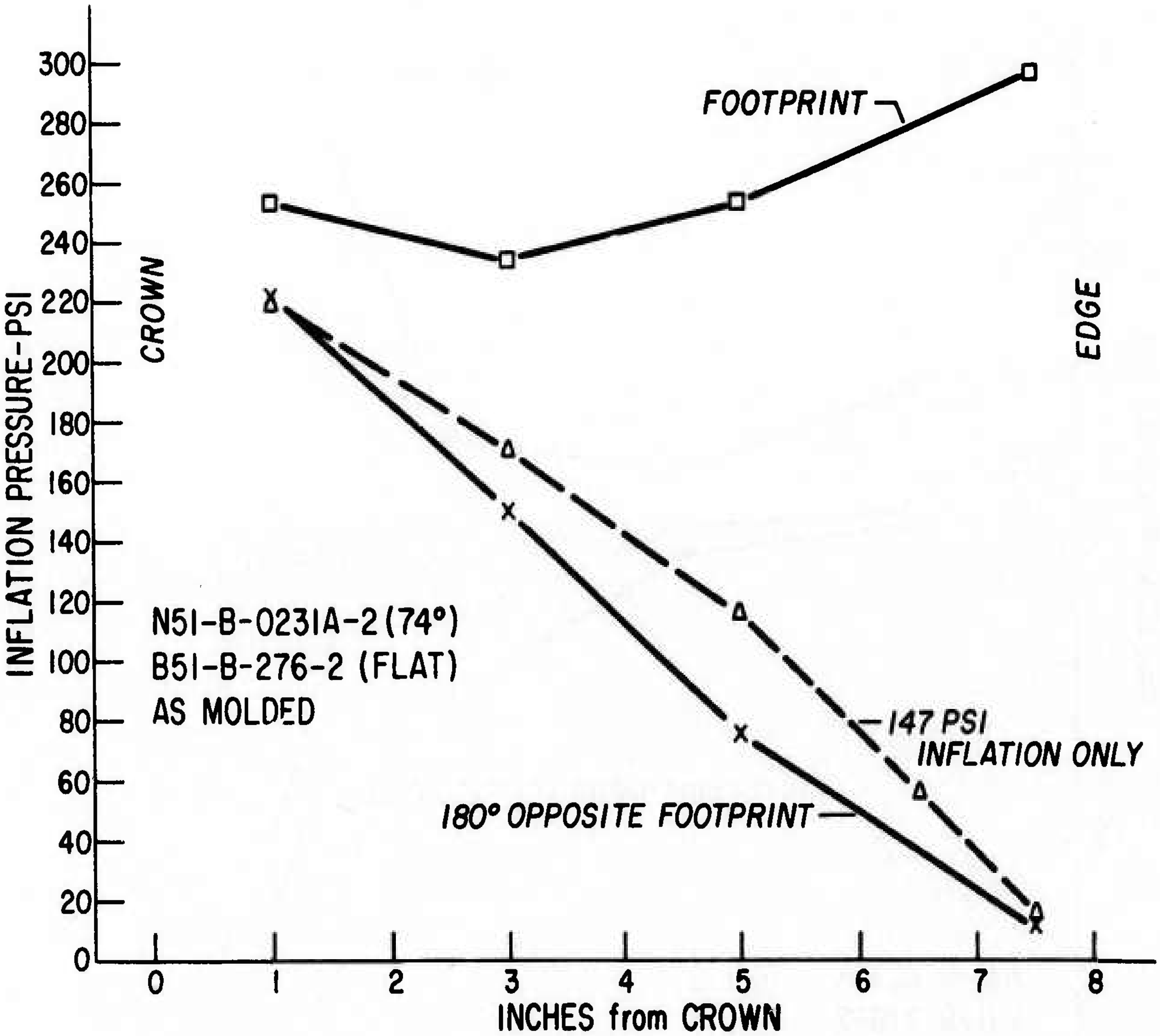

Figure32.EFFECT of LOAD on INTERFACE PRESSURE DISTRIBUTION of a 20.00-20 REPLACEABLE TREAD TIRE

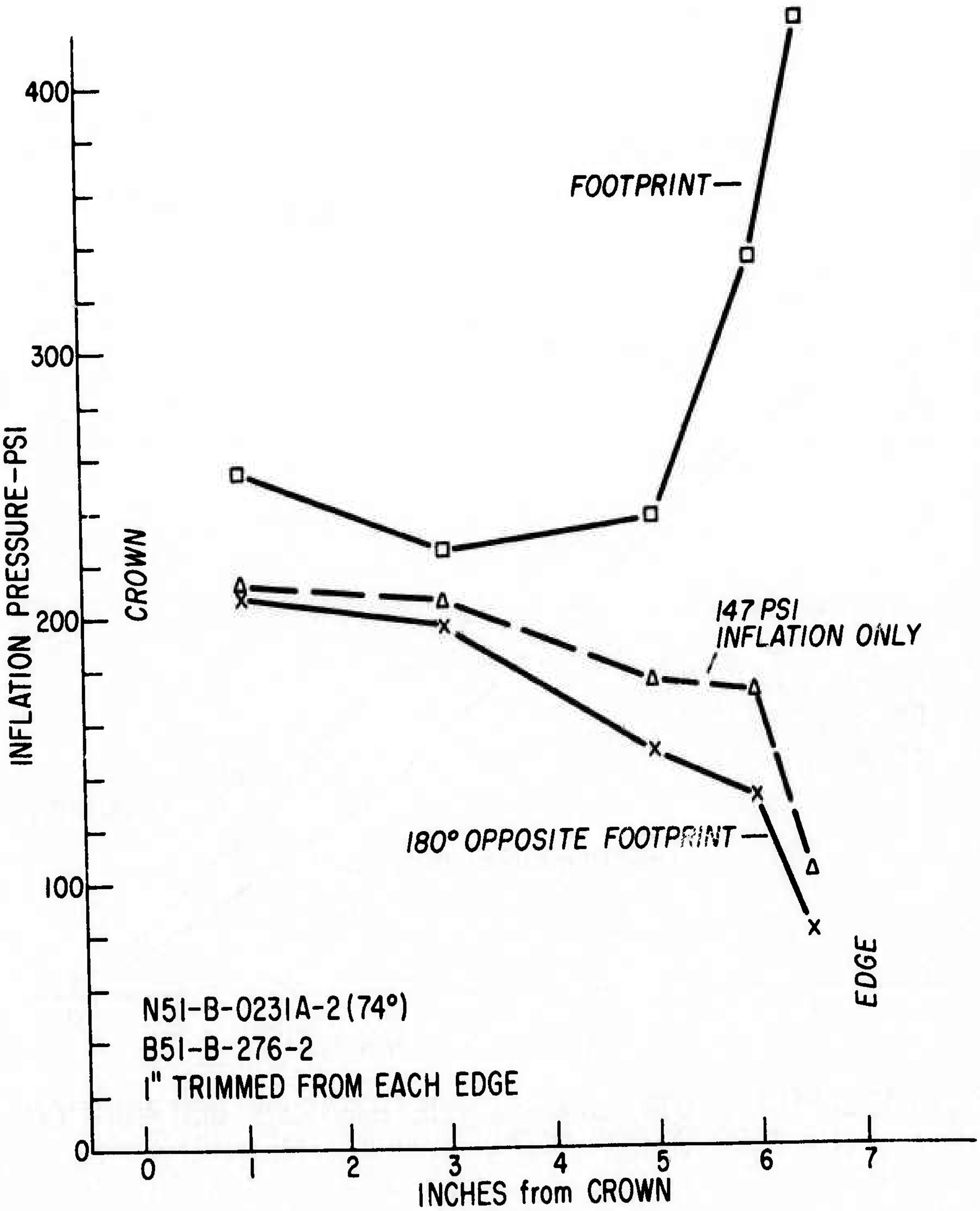

Figure 33. EFFECT of LOAD on INTERFACE PRESSURE DISTRIBUTION of a 20.00-20 REPLACEABLE TREAD TIRE-BELT TRIMMED ONE INCH

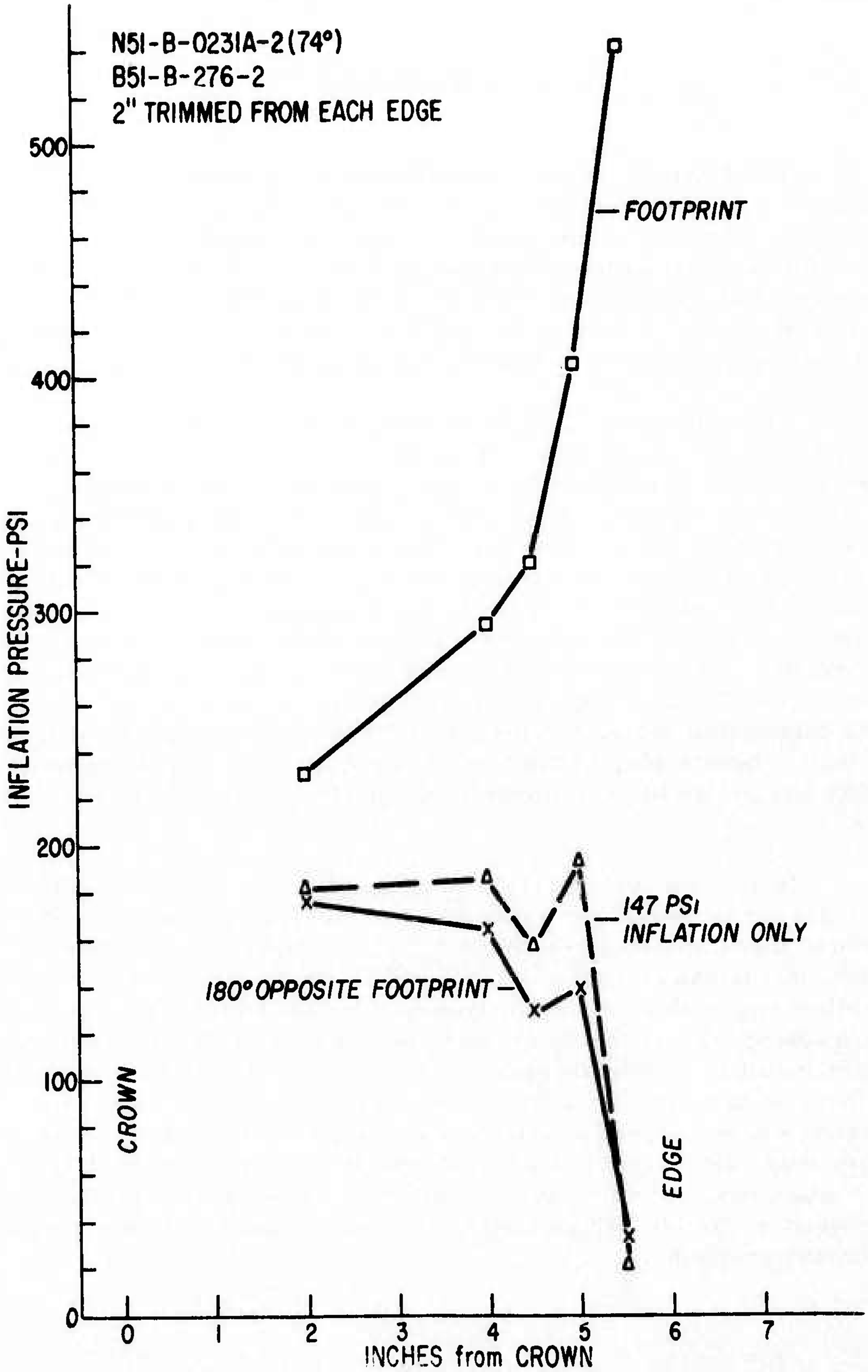

Figure 34. EFFECT of LOAD on INTERFACE PRESSURE DISTRIBUTION of a 20.00-20 REPLACEABLE TREAD TIRE - BELT TRIMMED TWO INCHES

3. DISCUSSION

The Phase II design, manufacturing and evaluation program emphasized several important facts. Perhaps the most significant was the number of major problems which appeared and the fact that, on the basis of prior experience with the 6.00-6 size, they were not expected. The sequential appearance of one problem immediately following the solution of another indicates the complex inter-relationships among the construction parameters and how a change in one affects performance.

The solution to the belt-splitting problem was to increase belt strength. As a result of this change the chafing problem appeared. When we reduced tread band diameter, and apparently reduced chafing, belt breaks and ply separations occurred. These two major problems remain unresolved at this time. The belt edge appears to be the most sensitive. Interface pressure measurements showed extreme pressure fluctuations at the belt edges during roll. The chafing was confined to the belt edges as was the scuffing. We observed carcass elongations, also in the belt edge region. The tissue paper results showed motion at the belt edges. It seems that the belt-edge/carcass-shoulder is the most significant part of the expandable carcass-replaceable tread tire concept. A more thorough understanding of the loads and elongations in this region could lead to significant improvements in the performance of replaceable tread tires.

In assessing the current problems of the 20.00-20 replaceable tread tire let us recall our experience on the 6.00-6 size. AFFDL-TR-73-84 stated that the single parameter which has the greatest influence on derailment was amount of interference. The same report also described two problems encountered in contract F33615-72-C-1361. These were gapping and excessive shoulder wear on a tire design which seemed to have insufficient interference. The current 20.00-20 tire does have problems in the shoulder area. Although no derailment has been experienced, the degree of interference is less than on the successful 6.00-6 size. This aspect of the replaceable tread concept is fully discussed in the Appendix, including benefits of lower aspect ratio, greater interference, flatter belt contours, etc. which could lead to a resolution of current problems.

4. CONCLUSIONS

The results of the effort to design, manufacture and evaluate the 20.00-20/26 PR expandable carcass-replaceable tread tire are as follows:

1. The objective of the Phase II program, i.e. to design, manufacture and evaluate for tread band retention and durability a total of eight different expandable carcass and tread band configurations in the 20.00-20 size, has been exceeded. We have designed, manufactured and subsequently evaluated a total of eleven different carcass and twenty-three tread band configurations.

2. Four completely new and unexpected major performance problems were encountered. The first, belt splitting, has been solved. The second, chafing, appears to be resolved but will require additional testing. The remaining two, tread band breakage and ply separations in the belt, have not been resolved.

3. Derailment, the area of greatest concern on the 6.00-6/8 PR expandable carcass-replaceable tread tire, was not a problem with the 20.00-20/26 PR tires evaluated in Phase II.

4. Current manufacturing techniques do not lend themselves to the large volume production of 20.00-20 expandable carcass-replaceable tread tires.

5. The dimensional requirements of MIL-T-5041F may not be compatible with the replaceable tread concept. Our prior studies of the derailment phenomenon indicated that those 6.00-6 expandable carcass-replaceable tread tires which did not derail exceeded the MIL-T-5041 F section width requirement. Our effort with the 20.00-20 has resulted in a current replaceable tread tire design which is smaller in diameter than MIL-T-5041 F requirements.

6. There is insufficient data relating to successful performance on the 20.00-20 size to establish a design criteria summary. The Appendix describes a range of parameters obtained from both 6.00-6 and 20.00-20 sizes.

5. RECOMMENDATIONS

Based on our recent Phase II experience with the 20.00-20/26 PR expandable carcass-replaceable tread tire and our prior knowledge of this concept acquired from the 6.00-6/8 PR replaceable tread tire, the following recommendations are made:

1. Conduct a mathematical-experimental study of the expandable carcass-replaceable tread concept, directed toward solving the belt break and ply separation problems. Such a study would provide a more basic understanding of the stresses and strains which have produced these failures.

2. Explore various tire sizes which would not meet MIL-T-5041F dimensional requirements when adapted to the expandable carcass-replaceable tread concept. The resulting tires would be designed to keep within the space envelope, carry the same load but with different inflation pressures as the MIL-Spec. tires.

3. Study the manufacturing techniques used to produce the expandable carcasses and replaceable tread bands. The goal of such a study should result in the capability to produce these tires in large volumes, in large as well as small sizes.

4. Continue with the 20.00-20 program as defined in the present contract but with the following two deviations: (a.) reduce aspect ratio from .91 to about .75 and (b.) increase tread radius from 12 inches to about 40 inches.

APPENDIX

THE REPLACEABLE TREAD 20.00-20 - AN OVERVIEW

In reviewing the result of the 6.00-6 program and the problems of the 20.00-20 program, it is apparent that the amount of carcass/belt interference is directly related to the performance of the tire.

For example, early in the 6.00-6 program, we had successful testing of the prototype tire. The tire unfortunately did not meet MIL spec for section width and so it was resized. Subsequent testing of the resized tire resulted in belt derailing . In order to attain the previously-realized performance level,we were given a deviation on dimensions and were allowed to manufacture the "wide section width" tire again. This tire met the test requirements.

The reason the "wide" tire worked was because the carcass exerted more pressure across the belt width. It is important to understand why this is so, because it bears directly upon the performance of the 20.00-20.

Belt/carcass interfacial pressure is related to aspect ratio -- and the lower the aspect ratio, the greater the pressure.

6.00-6	Original tire	81% aspect ratio - worked
	Rebuild	91% - failure- derailing and rapid shoulder wear
	Rebuild of orig.	81% aspect ratio - worked
20.00-20	Original tire	91% - belt chafing
	Rebuild	73% - much improved chafing

There is a need for the carcass to exert pressure on the belt to prevent derailing and minimize movement at the belt edge. The textile belt on these tires must be put into tension before it becomes stiff enough to act as a belt. The derailing and rapid shoulder wear of the 91% tire are both indications of inadequate belt tension caused by insufficient carcass/belt interference.

The amount of carcass/belt pressure generated depends upon many factors, some of which are:

(1) natural inflated O. D. of the carcass.
(2) the ratio of natural carcass O/D to belt band O. D.

(3) the final aspect ratio of the tire.
(4) carcass angles.

By tying together measurements taken during our work with the 6.00-6 and the 20.00-20 and utilizing a recently-developed tire sizing program, it is possible to predict the natural inflated diameter of a carcass and study the effects of carcass periphery, carcass angle and bead spacing upon this dimension.

By knowing the unrestricted natural inflated diameter of a carcass, and the diameter it will be restricted to by a belt band, it is then possible to calculate the interference between carcass and tread. This interference gives the belt/carcass pressure that causes these components to act as a unit rather than two separate parts.

In Phase II of the 20.00-20 contract, 44 carcasses were built in 11 different constructions, and 31 tread bands were built in 23 different configurations. The carcass/belt interference was also varied, as well as belt band width. An extensive program of analysis of interfacial pressures was completed.

At the beginning of the 20.00-20 program, there were many unknowns -- no one had ever attempted to manufacture a replaceable tread aircraft tire of such size. At the completion of Phase II of the contract, we now have a much better understanding of all the forces at work in this tire and can better assess the degree of design freedom we have when working with this concept.

Before proceeding with any future development work, we feel that it is wise to review our design goals and relate them to our present fund of knowledge. Knowing what we know now, it may be necessary to alter our present path in order to reach our original goals, if indeed they can be reached.

For this reason, we have asked ourselves six basic questions about the replaceable tread aircraft tire. We can answer these questions with reasonable assurance, based upon our background of Phase II 20.00-20 work, the previous 6.00-6 work and our knowledge of the present state of the art in radial passenger and radial truck tires.

These six questions are:

1. What is the minimum amount of carcass/belt interference necessary to make the concept work?

2. How does the need for this interfernce affect tire sizing?

3. What is the effect of carcass angle on tire sizing?

4. What is the effect of tread radius on tire performance?

5. What is the effect of belt angle on tire performance?

6. What is the optimum sizing/construction package?

Let's look at the questions one by one:

1. <u>What is the minimum amount of carcass/belt interference necessary to make the concept work?</u>

We already have some performance data from the 6.00-6 and 20.00-20 programs to answer this question. In both cases, we had to deviate from the MIL spec in order to improve performance.

In the case of the 6.00-6, the section width had to be widened out. This lowered the aspect ratio from the MIL spec 91% to about 81% and effectively increased the carcass/belt interference. This solved a derailing problem and reduced shoulder wear.

In the case of the 20.00-20, the belt band O. D. was reduced by 5 inches, again lowering the aspect ratio, this time to 73%. This reduced the amount of chafing in the belt edge area.

<u>To Summarize:</u>

	Aspect Ratio		Carcass/Belt Interference at Centerline	
Size	MIL	Redesign	MIL	Redesign
6.00-6	91%	81%	5.5%	10%
20.00-20	91%	73%	6.0%	14.5%

This indicates that the replaceable tread concept will not work within the dimensional restrictions of the MIL spec for Type III aircraft tires.

2. How does this need for carcass/belt interference affect tire sizing?

There is presently available at BFG a computer tire sizing program that will predict the natural inflated shape of a carcass. Carcass periphery, bead spacing and carcass angle can all be plugged into this program.

The output is a prediction of the unrestricted inflated carcass profile. When the diameter of the belt assembly is known, then it is an easy matter to calculate the theoretical interference between carcass and belt.

There are a number of different methods of increasing carcass/belt interference.

For example: to increase the inflated carcass diameter, one can increase the carcass periphery. This will generate more interference, but the extra carcass periphery will cause an increase in tire section width.

One can also increase the interference by reducing the belt diameter and keeping the carcass the same. The end effect of either change is the same -- a lowering of the aspect ratio of the tire.

There is no other way to put interference between the carcass and the belt other than making the natural unrestricted inflated diameter of the carcass larger than the final restricted diameter.

The greater the interference required, the greater must be the difference between the unrestricted and the restricted diameter of the carcass, and the lower the required tire aspect ratio.

3. <u>What is the effect of carcass angle on tire sizing?</u>

A 90° carcass will inflate to the greatest diameter. The lower the carcass angle, the more restriction there is on inflated O. D. An 80° carcass angle will, therefore, have a smaller inflated O. D. than a 90° angle carcass. Because of this, the belt assembly of an 80° tire would have to be of a smaller diameter than that of a 90° tire in order to maintain the same carcass/belt interference.

Therefore, the lower the carcass angle, the lower the required tire aspect ratio must be to maintain the same interference.

4. <u>What is the effect of tread radius on tire performance?</u>

From our experience on truck and passenger radials, we know that the flatter we can keep the belt, the better the tire performance.

The object is to minimize the deformation of the belt as it goes through the footprint.

The higher the belt angle, the "rounder" the belt we can tolerate. This is because the high belt angles allow the belt to "pantograph" and equalize out the deformation as it goes through the footprint.

On the replaceable tread tire, we are tied into a 0° belt angle, due to a derailing problem encountered with higher angles. Furthermore, the inflated belt radius is in the range of 12" to 13". When the tire is unloaded, the center of the belt touches the ground, but the belt edges do not. As load is applied, a change in diameter must take place -- either the cords in the center of the belt must buckle, or the cords in the belt edge must undergo tremendous tensions. We suspect that both conditions are present. To make matters worse, the 0° belt angle allows no pantographing.

We are in a design situation that could never be tolerated in either passenger or truck radials and find it doubtful that it would work in an aircraft tire with even higher stresses and loads.

It is, therefore, imperative that the tread profile design restriction be removed so that future work on this concept can be done in molds with a much flatter tread radius.

5. What is the effect of belt angle on tire performance?

To date, a 0° belt is the only one that has worked. This is because any belt significantly higher than 0° has derailed by "steering" itself off the carcass.

Zero Degree Belt	
Advantages	Disadvantages
Prevents derailing	Extremely difficult to cure since it cannot be "lifted" into a conventional mold. Tread bands must be "buckled" into a conventional mold. A sectional mold would solve this problem, but is expensive.

6. What is the optimum sizing/construction package?

Tread Radius	- Flat
Belt Angle	- Higher than 0° - if we can prevent derailing.
Carcass Angle	- For performance 90°. For building large tires 75°.
Aspect Ratio	- No higher than 80% - 60-70% may be required. Since the section width is restricted, we must lower the aspect ratio by lowering tire O.D.
Carcass Mold Configuration	- This means smooth sidewall rather than convoluted to allow manufacture.
Equipment	- New carcass and belt molds required.
Inflation Pressure	- Higher inflation pressure required because of smaller contained air volume (smaller tire O.D.). Also increased inflation may be required to reduce tire deflection.

In the 20.00-20 replaceable tread aircraft tire, we are working in an area where little previous knowledge existed.

Based on our work to date, we feel that we must proceed in a different direction if there is to be any hope of success in this project. To continue on the present path would be technically unwise since a number of natural physical laws would have to be violated for the present "package" to work.

The major deviation from the present program we feel must be made is in the inflated shape of the tire.

The present tire is a 91 aspect ratio with a 12" inflated tread radius. We feel that an aspect ratio in the range of 75% to 80% will be required along with a tread radius in the range of 30" to 50".

Let me repeat that we see a minimal chance of producing an acceptable 20.00-20 within the restrictions of the present contract. This is not due to a lack of urgency, desire or techology, but is simply due to the fact that certain natural physical laws prevent us from accomplishing our task within the present dimension limitations.

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